WEATHER SCIENCE FOR EVERYBODY

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BY

DAVID BRUNT, M.A.

Professor of Meteorology in the University of London

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PREFACE

I HAVE written this book in the belief that there are many who are interested to know something of the causes which underlie the weather, but who have no special desire themselves to become weather prophets. I have therefore tried to give as simple an account as possible of some of the phenomena of weather, and of their bearing on human life. Meteorology, which Aristotle defined as the "science of things in the air," is a very complicated subject, which makes use of many highly technical concepts, some of which cannot be put into simple terms. It cannot therefore be expected that any simple book can tell "all about the weather." I have restricted the discussion of weather forecasting to one short chapter, believing it to be more useful to give the reader some idea of how he may determine if the official weather forecast is working out as anticipated than to encourage him with the vain idea that he may himself improve on the official forecast. I hope that the description I have given of the organization behind the official forecast service will suffice to show the magnitude of these "noises-off," and will show also that the private individual is unlikely to improve on the results obtained by the official services.

There appear to be two principles which should be

followed by the author of such a book as I have attempted to write. In the first place, the book must be accurate; its facts must be correct, and there must be no inaccurate analogies introduced for the sake of dramatic effect. This is a necessary condition if the reader who is sufficiently interested to wish to pursue the subject further is not to be forced to start his deeper study by unlearning some of the ideas he has acquired at his initial attempt. Secondly, the book must be written in a connected form, so that the reader who wishes to refer back to any item of information may be able to trace it without having to read through the whole book. I hope that no substantial inaccuracy has crept into the present book, and I have endeavoured, both in the arrangement of the text and by the provision of an index of the contents, to make it possible for the reader to refer readily to any part of the book at will.

There are some parts of the subject of meteorology which cannot be discussed clearly without mathematical reasoning, and these parts of the subject are omitted here. I have tried to give an account of those aspects of weather which have a close and direct bearing on the life of man. Portions of the last chapter presented considerable difficulty, as there is no general agreement on some of the points raised therein. The relations of weather and climate to health and comfort cannot be specified in their entirety. A complete statement of these relations will not be possible until much fuller investigations of the effects of weather and climate on human beings have been carried out. It is to be hoped,

however, that even the brief account given in the last chapter of this book may help the reader to a clearer idea of the way in which weather influences the life of man.

I am much indebted to my friend Mr. C. J. P. Cave for the four photographs of clouds reproduced in this volume. The photograph of lightning flashes which appears as a frontispiece is reproduced by kind permission of the Council of the Royal Meteorological Society. The photomicrographs of snow crystals, taken from the published collection by Bentley and Humphreys, are reproduced by kind permission of the McGraw-Hill Publishing Company.

Of the diagrams in the text, figures 13, 14, and 15 are reproduced by the courtesy of the Cambridge University Press, and figures 11, 16, 18, 19, 20, and 21 by the courtesy of the Oxford University Press, all being taken from books of which I was either author or part author.

D. BRUNT.

Imperial College of Science and Technology,
London, S.W.7.
March 9, 1936.

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CHAPTER I

WEATHER AND HUMAN AFFAIRS IN PEACE AND WAR

"What is it moulds the life of man?
The weather.
What makes some black and others tan?
The weather.
What makes the Zulu live in trees,
And Congo natives dress in leaves,
While others go in furs and freeze?
The weather."

W. J. HUMPHREYS
(*Weather Proverbs and Paradoxes*).

EVIDENCE of many kinds has shown that there have been great changes in the climate of parts of the earth in the past. These changes culminated in the ice ages, during which large parts of the northern hemisphere were covered by glaciers. The last ice age is estimated to have occurred about 40,000 to 18,000 B.C., though the dating of this is to be taken as only a very rough estimate. The changes in the conditions of life brought about by the ice ages were far-reaching, and the only human race which survived was *Homo Sapiens*, modern man. The Neanderthal or Mousterian man, closely resembling modern man, who lived before the last ice age, failed to adapt himself to the changing conditions, and so perished. If we go back to the last ice age but one (say, 130,000 to 100,000 B.C.) we find again that of the two races of man known to exist before the ice came,

only one, the Heidelberg man, contrived to survive; the other, the Piltdown man, having perished. It cannot be said with certainty that it was the intense cold brought about by the ice ages which was the sole factor in the extermination of the races that failed to survive. Drought may also have been a potent factor. But it is certain that only the races of the highest intelligence and stamina could survive the drastic changes in the conditions of life which the ice ages brought in their train.

Other changes of climate, affecting less extensive regions than did the ice ages, have taken place in different parts of the world. Ruined cities have been found in regions which are now desert—in Arabia, in Central Asia, and in the desert of Arizona—showing that at one time these regions must have been fertile; while the marble ruins of Angkor, in the jungle of Cambodia, and the cities of the Mayas, in the jungle of Central America, bear witness to a marked increase in rainfall, leading to profuse growth of jungle. There is strong evidence that during the past two thousand years the continent of Asia has become increasingly arid, with deserts developing in regions which were once fertile. Going back still farther, it is surmised that man originated in Central Asia, then a well-watered plain covered with forests which later on, in consequence of the gradual elevation of the Himalayas, became progressively more arid, the forest-land giving way to steppe. One can conjecture that only the most adaptable races could survive these changes, which thus became a potent factor in the evolution of man.

It has been reasonably well established that from about 2000 B.C. to about A.D. 500 there was a long period of relatively high rainfall in Europe and Asia, and it was during this period that the Mediterranean

races attained a development the highest level of which was shown in the heroic age of Greece. The end of the period of high rainfall seems to have contributed to a loss of energy of the Mediterranean races, and to the downfall of the Mediterranean empires. Modern research appears to show that the downfall of Greece was associated with an epidemic of malaria, which attacked almost the whole nation; but it must be borne in mind that the vitality of the people had probably diminished as a result of the increasing mildness of the climate, leaving them ready victims of the epidemic.

The downfall of the empires of Greece and Rome was largely due to the incursions of the barbarians from the East. These in turn had been driven westward by the general movement of races from Central Asia, forced by the increasing aridity of their native continent to seek a fresh country. For many centuries the peoples of Central Asia were vigorous and warlike, their constant migration in search of fresh pasturage for their horses leading to perpetual conflict among the different tribes. Of all these races perhaps the most remarkable were the Mongols, who in the early thirteenth century had established an empire reaching from Korea to the Persian Gulf. This empire might have been extended into Europe but for an untimely death. About A.D. 1240 a Mogul army invaded Europe, and easily swept everything before it; but at a critical moment the Mogul emperor died suddenly, and the Mogul general who commanded the invading forces in Europe hastily returned home with his army in order to press his own claim to the throne. The energy and hardiness of this army were almost incredible. On one occasion Mogul mounted men covered the 180 miles from Lemberg to Gran, over country deep in snow, in three days.

A nation's religion may be moulded by climate. An example of this is to be found in the custom of embalming the dead in ancient Egypt. The Egyptians of about 4000 B.C. knew that human bodies were perfectly preserved if buried in the hot, dry sand, and it is probable that it gradually became a religious belief that such preservation was necessary if the dead person were to attain immortality. When with the development of civilization influential families began to construct large rock tombs to take the place of graves dug in the sand, it was found that the bodies were no longer naturally preserved, and artificial methods of preservation had to be found, leading in time to the elaborate process of embalming.

It appears that the ancient civilizations developed in well-watered regions in which the climate was mild and equable and the cultivation of food was relatively easy. This was certainly true of the Egyptian civilization which developed in the valley of the Nile, of the Babylonian civilization which developed in the valley of the Euphrates, and of the Chinese civilization which developed in the valley of the Hwang-Ho. Civilization spread from Egypt and Babylon to the northern shores of the Mediterranean during the period of plentiful rain to which we have already referred. The further spread northward did not come about until the general use of coal as a fuel made it possible to some extent to control the rigours of winter.

But while the climate of a country can have a slow but overwhelming influence on the character, vigour, and religion of its people, the weather can, by its occasional extremes, produce disaster even within a few days. Both in peace and war weather can influence the lives and well-being of men. Severe weather in winter or

spring. or excessively wet summers, may destroy crops and bring famine. Records of severe weather can be traced in a scattered form in many books, though we are often left to guess what may have been the economic consequences of these visitations. Holinshed records that the winter of 1436 was so cold that ale and wine were sold solid by weight, to be melted before consumption. This cold winter was followed by a severe famine in 1437–8.

Over the whole of Europe the winter of 1788–9 was intensely cold. The Seine was frozen from the end of November 1788 till nearly the end of January 1789, and the average temperature in Paris during the month of December 1788 was 20° F. The intense cold and the subsequent thaw produced enormous damage in all parts of France, vines and fruit trees being killed by the frost, and the fish dying in nearly all the ponds. This severe winter was followed by a famine in France, and it can be readily imagined that the misery it brought helped to precipitate the French Revolution in 1789.

Even the somewhat accidental occurrence of high winds at a crucial time may be fraught with the gravest consequences. The great fires which ravaged London in 1666, Hamburg in 1842, and Chicago in 1871 were all fanned by high winds, which helped to spread fire over a wide area. The Great Fire of London followed a long period of warm dry weather, the effect of which on a city consisting so largely of wooden buildings would be to make it burn like matchwood.

Even in the most modern conditions human activity can be reduced to a minimum by thick fog or heavy snow, which are the greatest enemies of all forms of movement. No one who has lived in London can fail to appreciate the effect of continued fog. As recently as

February 1929, parts of the British Isles were isolated for days by a fall of snow, and the shortage of food became acute in a number of isolated places.

Weather can affect the course of war in many ways—by killing the soldier, and particularly the wounded soldier with cold; by destroying his mobility through excessive rain or sudden thaw; by increasing his mobility through drought or sudden frost; by hiding his movements in fog; by parching him with excessive heat; or by drowning him or his transport at sea. History affords plentiful examples of all these, and the student of history cannot fail to conclude that there is no feature of war which may not be hindered or rendered impossible by unfavourable weather, or facilitated beyond expectation by favourable weather. As a general rule, we may say that in war fog favours an attacking force, or a defeated army in escaping, while heavy rain or snow favours the defending force. Violent storms at sea hinder any exposed fleet. In naval warfare under modern conditions poor visibility favours the fleet with the best armoured protection, while good visibility favours the fleet with high speed and long-range guns.

It is not difficult to find historical examples of the effects in warfare of chance occurrence of fog, rain, storms, etc.—chance occurrences on which have hinged events that have changed the destinies of nations. It is by no means uninstructive to consider how history might have followed a different course had some apparently casual fog or storm not occurred at a particular time. The history of the campaigns of any great general, except perhaps those of the Duke of Marlborough, will afford plentiful examples of such casual disturbances. The present writer has failed to find in any account he has seen of the campaigns of Marlborough any reference to

ill effects of weather. One gains the impression that the great Duke's plans were incapable of disturbance by any natural phenomenon, and that they marched magnificently to their predestined conclusion no matter what the weather.

It would be easy to fill the whole of the present volume with examples of the influence of weather on particular military operations, but space does not permit of more than a few examples. The Norman conquest of England in 1066 was vitally affected by the high winds which kept William weather-bound in port for six weeks. While Harold was awaiting him on the south coast of England word was brought that Harald Hadrada had landed on the north-east coast, and Harold had to march northward to meet this invader, whom he defeated at Stamford Bridge. Three days after the battle, William landed at Pevensey, and Harold hurried southward with only a part of his forces. Even then, with an army sadly depleted by losses at Stamford Bridge and wearied by forced marches, Harold lost the battle of Hastings only by a very narrow margin. It is not unfair to assume that had William not been delayed, so that Harold might have met him with fresh and undepleted forces, the result of the battle of Hastings would have been reversed and the Norman conquest would not have materialized. For Harold possessed in his light cavalry what was regarded as the finest fighting unit of his day, and the lack of reserves to throw into the battle when William's cavalry attack had failed decided the fortunes of the day.

On a day in 1799 a fog in the Mediterranean enabled Napoleon, then returning from Egypt with only two frigates, to pass unseen through the British patrolling fleet under the command of Nelson, and to land in safety

in Provence. Ludwig states in his *Life of Napoleon*[2] that it had been decided to blow up the frigate which carried Napoleon rather than surrender to the English, and the kindly fog which hid the frigate saved the life of Napoleon. At that time the Napoleonic wars were yet to come, so that it is no exaggeration to say that the fog had a marked influence on the course of history. There were other occasions on which fog played a deciding part in the fortunes of Napoleon, as for example at Jena and Auerstadt in 1806, when fog enabled him to take up positions from which an attack could be launched later with devastating effect, and when he captured the Somosierra Pass, hitherto considered impregnable, by launching a sudden attack in a fog.

Every reader of history will be familiar with the destruction by storms of the Spanish Armadas which set out to conquer England in 1588 and 1597. The history of ancient Greece affords a parallel, the Persian fleets which assisted the attacks by land on Greece in 493 B.C. and 490 B.C. being partly destroyed and completely demoralized by the sudden storms which came upon them.

In the wars of the future, if such there be, weather will be a vitally important factor. The influence of wind and weather on flying operations, of visibility on gun-ranging and bombing, of wind and temperature on the use of smoke screens and of chemical warfare generally, of rain and sudden thaw on land transport, may at any moment become the deciding factor.

CHAPTER II

WEATHER OBSERVATIONS AND WHAT THEY MEAN

THE AIR AROUND US

ORDINARY air as we know it contains an amount of water in the form of gas or vapour which varies greatly from time to time and from place to place. For convenience in discussing weather changes, ordinary air may be regarded as being made up of a mixture of dry air (containing no water-vapour) with a varying amount of water-vapour added to it. Dry air is a mixture of gases, of which oxygen forms 21 per cent. and nitrogen 78 per cent., while carbon dioxide, traces of hydrogen, and the inert gases argon, helium, neon, krypton, and xenon account for the remaining 1 per cent. This mixture appears to be always in the same proportion, at least up to such heights as are accessible to direct sampling, except for local pollution by carbon dioxide and chimney gases. The only constituent of ordinary air which shows any variation in its amount is water-vapour, the gas which is produced when water evaporates, and it is the variation in the amount of water-vapour which accounts for most of the uncertainty of weather.

DAMP AIR

The water-vapour in the air is so important that we must start our study of the weather by trying to under-

stand some of its vagaries. If a kettle full of cold water is placed on a lighted gas-jet, the water is gradually warmed, until its temperature reaches the boiling point, at 212° F. at the earth's surface. The temperature does not then rise any further, and all the heat conveyed to the water from the gas-jet is used in turning the liquid water into an invisible vapour, steam. The heat used in converting liquid water into vapour is called *latent heat.* It becomes available for other purposes when the vapour is again condensed into liquid water. The actual amount of heat required to turn a pound of water into vapour is between five and six times the amount of heat required to raise a pound of water from the freezing point to the boiling point.

The greatest amount of water-vapour which can be put into a given volume—say a cubic-foot box—depends only on the temperature within the box, and is the same no matter how much dry air there may be in it. Air which contains the maximum amount of vapour is said to be *saturated.* When air contains less than this maximum amount it is said to be *unsaturated,* and the percentage of the maximum amount of water-vapour which it contains is called its *relative humidity.* Thus in air of relative humidity 50 per cent., there is in each cubic foot exactly half the amount of water-vapour which it can be made to contain at that temperature.

It has been mentioned that water boils at a temperature called the *boiling point,* which at the earth's surface is about 212° F. But when water is exposed to the air, no matter what the temperature may be, some of it will evaporate and enter the air as invisible vapour, provided the air near it is not saturated. If the air is already saturated, the water cannot evaporate. That this is so is familiar to every housewife, who knows that wet clothes

hung in the open will not dry on days when the air is very damp. The housewife's ideal drying day is one when the air is dry and there is a breeze capable of removing quickly the air made damp by the evaporation of the water from the clothes, and replacing it by dry air.

The evaporation of water is continually taking place, not only from the sea and other water surfaces, but also from grass and foliage. So active is the process that it is estimated that in a day the equivalent of a sheet of water about one-twelfth of an inch in thickness over the whole surface of the earth, both land and sea, is evaporated.

PRESSURE AND TEMPERATURE

The bubble of air which may sometimes be seen clinging to the side of a glass filled with water contains several times ten thousand million million atoms, each about a hundred-millionth of an inch in diameter. About a fifth of these are atoms of oxygen, and nearly all the others are atoms of nitrogen. It has been found that atoms of most simple substances are not capable of staying isolated, and that they collect together into small groups known as molecules. Thus atoms of oxygen usually join up in pairs, giving oxygen in the state in which it is normally found in the atmosphere. More rarely, and then only in special conditions, the oxygen atoms combine into groups of three, giving what is known as ozone. In nitrogen, hydrogen, chlorine, and most other simple substances, or *elements* as they are called, the molecules are groups of two atoms, but in some substances the atom can exist alone—as, for example, in argon or mercury. More complex substances, which are compounds of two or more simple substances or elements, may contain widely varying numbers of atoms in the

molecule. Thus the molecule of water contains two atoms of hydrogen and one of oxygen, while the molecule of alcohol contains nine atoms, two of carbon, six of hydrogen, and one of oxygen.

The molecules of which matter is made are in perpetual movement. If we think of a vessel containing a certain amount of air, the molecules inside it are in a state of continual agitation, jostling each other like a crowd of people in a demented state, and occasionally hitting against the walls of the vessel. The heat of a gas is nothing more than the energy of the motion of the molecules, and it is the total impulse of the impacts on the walls which measures the *pressure* inside the vessel. This pressure will depend on the speed with which the molecules are rushing about, and also on the total number of molecules inside the vessel.

In the free atmosphere a column of air extending from any chosen level up to the top of the atmosphere will be held up by the impacts on the bottom of the column of the molecules below it. So the pressure, which we have agreed to define as the sum-total of the blows on the base, must balance the weight of the column. The greater the weight of the column, the greater will be the pressure on its base required to keep it up. What is known as the pressure of the atmosphere is thus very simply defined as a measure of the weight of air in a column of air extending from the level at which the pressure is being considered up to the top of the atmosphere. And so, when an official weather forecast speaks of pressure falling over our western coasts, we may interpret this as meaning that, for some reason or other, the amount of air over each square foot along our western coasts is decreasing. It may be added at this stage that the greatest difficulty with which the weather expert is

faced is to explain why and how this removal of air from any region takes place.

MEASURING THE PRESSURE

There are two familiar instruments for measuring the pressure of the air, called the mercury barometer and the aneroid respectively. The earliest form of the mercury barometer consists of a J-shaped tube, closed at the upper end of the longer leg, and open at the upper end of the shorter leg. The pressure of the air on the mercury in the open end of the tube—or, in other words, the continual bombardment of the mercury by the molecules of the air—keeps the mercury up in the long leg of the tube. If, then, we take account of the fact that the pressure also measures the weight of the air in a column extending to the top of the atmosphere, we can define a barometer as a device for weighing this column by balancing it against a column of mercury. So the pressure is actually measured as the length of a column of mercury.

The aneroid barometer is in essence a flat metal box, from which nearly all the air has been pumped out. The pressure of the outer air compresses the box, and, as the pressure of the outer air changes, the degree of compression of the box changes. If the pressure rises, the walls of the box are pressed closer together. If one wall of the box is fixed, the other will move towards or away from it as the pressure rises or falls, and the motion of the free wall is magnified by means of a lever. This lever can be made to move a hand over a dial, as in the wall aneroid barometer, or it can be made to move a pen over a revolving drum, as in the ordinary *barograph*, which gives on a chart a continuous record of changes of pressure.

Something must be said here as to the units in which pressure is measured. On the older barometers, the scales were always graduated in inches in English-speaking countries, and in millimetres on the continent of Europe. The average pressure of the atmosphere at the earth's surface is about 30 inches or 760 millimetres of mercury. (1 inch = 25·4 millimetres.) It has now become a more general custom to measure pressure in millibars, which are such that the average pressure shown on a weather chart is about 1013 millibars. A millibar may be defined as a force sufficient to give a mass of 1 kilogramme an acceleration of 1 centimetre per second per second.

TEMPERATURE AND HUMIDITY

The temperature of the air is measured by means of a thermometer, usually the ordinary type of mercury-in-glass thermometer. Care has to be taken that the bulb of the thermometer is shielded from the direct rays of the sun, and for this reason it is normally kept inside a screen, which is a wooden box with louvred sides allowing the free passage of air into and out of the space in which the thermometer is placed. The inside of a well-ventilated screen takes up the temperature of the air which passes through it, and so the *shade-temperature,* as the temperature measured inside the screen is usually named, is the temperature of the air.

The humidity of the air can be found with the help of another thermometer, the bulb of which is covered with muslin, having a wick fastened to the muslin and dipping into a vessel containing water. The wick keeps the muslin wet, and the evaporation of the water from the muslin cools the bulb of the thermometer, so that the temperature

of the "wet-bulb" thermometer, as it is called, generally reads lower than the ordinary or "dry-bulb" thermometer. From the readings of the dry- and wet-bulb thermometers the relative humidity of the air can be readily deduced by the use of tables. Alternatively, the relative humidity can be deduced from such a diagram as is shown in Fig. 1 below.

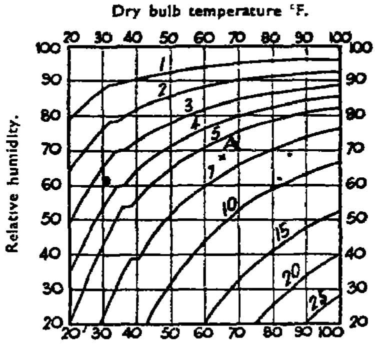


FIG. 1. HUMIDITY DIAGRAM.

The lines labelled 1, 2, 3, etc., indicate the difference between the dry- and wet-bulb thermometers. To find the relative humidity find the point where the vertical line through the appropriate dry-bulb reading cuts the line of the observed difference between the dry- and wet-bulb thermometers, and read the value of the relative humidity scale opposite this point. Thus with dry bulb 65°, wet bulb 59°, or 6° lower, the point A, taken halfway between lines 5 and 7, gives the relative humidity as 68%.

The screen in which the thermometers mentioned are housed at an official meteorological station also contains other instruments—notably the special thermometers which record the maximum temperature and the minimum temperature since they were last set. These instruments, which are laid nearly horizontal, contain small

rods, either within or without the column of liquid. The rods move with the liquid in one direction only, and are left behind when the liquid moves in the opposite direction.

A continuous record of temperature is obtained by means of a *thermograph*, consisting of a coil of two metals, which opens or closes as the temperature changes.

SCALES OF TEMPERATURE

In English-speaking countries temperature is measured on the Fahrenheit scale, on which the freezing point of water is at 32°, while the boiling point of water at normal pressure is at 212°. On the continent of Europe, and in some other parts of the world, temperature is measured on the Centigrade scale, on which the freezing point is at 0° and the boiling point at 100°. It is customary to distinguish the scale used by adding the capital letter F. or C. after the number of degrees. We may thus speak of the freezing point as 32° F. or as 0° C. Note, too, that an interval of 5° C. is equal to an interval of 9° F. To convert °F. into °C. subtract 32, and then multiply by 5/9. To convert °C. into °F. multiply by 9/5 and add 32.

Physicists have found that the lowest temperature which can exist is −273·1° C. This temperature is known as "absolute zero." The *absolute temperature* is the temperature measured on a scale the zero of which is at absolute zero, and which reads 273·1° at the freezing point and 373·1° at the boiling point of water.

RAINFALL

The amount of rainfall during a given period is measured by means of a rain-gauge, which is a vessel fixed below a

funnel of standard size. The rain which falls into the funnel runs into the vessel below, and the amount which has fallen since the last observation is measured by pouring the accumulated rain into a glass measure, on which is graduated a scale which gives directly the amount of rainfall in inches or millimetres. The rain-gauge should always be exposed in an open situation removed from the shielding effects of trees and buildings. Note that an inch of rain means 100 tons of water per acre, or about 65,000 tons to the square mile.

WIND

The motion of air, known as wind, can be observed in a number of ways. In the absence of instruments, it is possible to estimate the strength of the wind by its effects on surrounding objects. Such estimates are usually given, not in miles per hour, but on what is known as the Beaufort scale, so called after Admiral Beaufort, who first proposed the scale. The Beaufort scale was first devised for use at sea, and gave the specifications of the wind in terms of the sail which a fishing-smack could carry. It has since been revised for use on land, and the details are given in the table below. By careful use of this table it is possible to become expert in the estimation of wind without the use of any instrument.

Many types of instruments have been devised for the measurement of wind, and for giving a continuous record of its velocity and direction. The cup anemometer consists of four hemispherical cups at the ends of two crossed arms of metal, the cross being pivoted at its central point so as to be free to rotate horizontally. The difference of pressure inside and outside the cups causes the cross to spin round. The recording arrangement of

The Beaufort Scale of Wind Force, with Specifications and Equivalents

Beaufort Number.	*General Description of Wind.*	*Specification of Beaufort Scale.*		*Limits of Velocity in miles per hour at about 30 feet above level ground.*
		For Coast use.[1]	*For use Inland.*	
0	Calm.	Calm.	Smoke rises vertically.	Less than 1.
1	Light air.	Fishing-smack just has steerage way.	Wind-direction shown by smoke drift but not by wind vanes.	1–3
2	Slight breeze.	Wind fills the sails of smacks, which then move at about 1–2 miles per hour.	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7
3	Gentle breeze.	Smacks begin to careen and travel about 3–4 miles per hour.	Leaves and small twigs in constant motion; wind extends light flag.	8–12
4	Moderate breeze.	Good working breeze; smacks carry all canvas with good list.	Raises dust and loose paper; small branches are moved.	13–18
5	Fresh breeze.	Smacks shorten sail.	Small trees in leaf begin to sway.	19–24
6	Strong breeze.	Smacks have double reef in main sail.	Large branches in motion; whistling in telegraph wires.	25–31
7	Moderate gale.	Smacks at sea lie to.	Whole trees in motion.	32–38
8	Fresh gale.	All smacks make for harbour.	Breaks twigs off trees; generally impedes progress.	39–46
9	Strong gale.	—	Slight structural damage occurs; chimney-pots removed.	47–54
10	Whole gale.	—	Trees uprooted; considerable structural damage.	55–63
11	Storm.	—	Very rarely experienced; widespread damage.	64–75
12	Hurricane.	—	—	Above 75

[1] The fishing-smack in this column may be taken as representing a trawler of average type and trim.

this instrument usually gives the number of miles of wind which have passed since the instrument was started; but it is also possible to connect the rotating arm with a device similar to the speedometer of a motor-car, so as to obtain the instantaneous speed of the wind.

The standard type of anemometer used at meteorological stations reporting to the Meteorological Office, London, consists of a vane having an open end facing into the wind, and a double tube passing from the head to a specially shaped closed vessel floating in water. As the wind rises and falls, the float rises and falls, its motion being recorded by means of a suitable arrangement of levers and a pen. The direction in which the vane is pointing at any instant is transmitted downwards by means of a rod which passes centrally down the mast. The rotation of the rod is recorded on the same sheet as the velocity, by means of a suitable arrangement of cams and rods.

Specimen records of wind velocity and direction are shown in Fig. 15 on page 86. It is seen that the wind is never steady, but fluctuates continuously, both in speed and direction. The speed shows a succession of gusts and lulls. The main reason for the lack of steadiness of the wind is the disturbance to even flow by obstacles at the ground, which produce what are known as *eddies* in the flow. The pattern of the eddies, as shown by the smoke from a garden bonfire or the smoke from a factory chimney, is never steady for any length of time. Another reason for the irregularity of the wind is to be found in the fact that there are considerable variations in the temperature and humidity of the air which passes a given point in the course of a few minutes; while on hot afternoons the air near the ground may become so much hotter and lighter than the air above it that it tends to

burst upwards in bubbles, the place of the rising air being taken by faster-moving air descending from above.

VISIBILITY

It is important, particularly for aviation, to record the farthest distance at which objects on the ground are visible. At a meteorological station a number of objects at varying distances are selected, and the observer notes at each time of observation the most distant of the selected objects which is then visible, reporting the observation in the form of a code number. The code now employed, by international agreement, is shown in the table below.

Scale of Visibilities

0	Dense fog .	Objects not visible at :		55	yards
1	Thick fog .	,,	,,	220	,,
2	Fog . .	,,	,,	550	,,
3	Moderate fog .	,,	,,	1100	,,
4	Mist or haze .	,,	,,	$1\frac{1}{4}$	miles
5	Poor visibility .	,,	,,	$2\frac{1}{2}$	,,
6	Moderate visibility	,,	,,	$6\frac{1}{4}$	,,
7	Good visibility	,,	,,	$12\frac{1}{2}$	,,
8	Very good visibility	,,	,,	31	,,
9	Excellent visibility : Objects visible beyond 31 miles.				

WEATHER

Under the heading of weather, the observer reports the occurrence of rain, snow, or hail, the state of the sky, how many tenths of the sky are covered with cloud, and the type of cloud (see Chapter VI), both for the time of observation and for the interval since the last observation. He also reports the state of the ground—whether dry, wet, flooded, covered with ice, snow, glazed frost, or

frozen hard and dry. If his station is on the coast, he also reports the state of the sea—whether calm or rough. A portion of the Beaufort weather code is shown below.

The Beaufort Weather Code

- *b.* Blue sky, cloudless, or not more than one-quarter covered.
- *bc.* A combination of blue sky with detached clouds.
- *c.* Sky mainly cloudy, but with openings between the clouds.
- *o.* Sky completely overcast.
- *g.* Gloom.
- *r.* Continuous rain.
- *d.* Drizzle.
- *s.* Snow.
- *p.* Passing showers.
- *h.* Hail.
- *q.* Squalls.
- *l.* Lightning.
- *t.* Thunder.
- *f.* Fog.
- *m.* Mist.
- *z.* Dust haze.
- *v.* Unusual Visibility.

The above are the more common of the abbreviations used, but the complete list includes several other abbreviations for less common occurrences.

REPORTING TO HEADQUARTERS

The observer who has carried out a complete series of observations sends his observations to his headquarters office in the form of a message which consists entirely

of groups of five figures, with perhaps a few letters of the alphabet at the end. Thus at 7 a.m. G.M.T. on July 1, 1935, the meteorologist at Pembroke sent in his report as follows:—

13957	03744	01529	15155	9–803
11171	004—	6254.		

This means that at the time of observation, at Pembroke, the barometer read 1015·1 millibars, and had fallen 6 millibars in the last three hours. The wind was north by east, force 5. The temperature was 55°, and the relative humidity 95 per cent. The visibility was coded as 7, showing that the most distant object which was clearly visible was at a distance of between $6\frac{1}{4}$ and $12\frac{1}{2}$ miles. Of the sky nine-tenths were covered with cloud, between four- and six-tenths being covered with low cloud, a layer of stratus or strato-cumulus, with its base about 1500 feet above the ground; the rest of the sky was covered with cloud of type alto-cumulus or alto-stratus. The sea was smooth, and the ground wet. The lowest temperature during the preceding night was 54°; 11 millimetres of rain had fallen since 6 o'clock on the preceding evening, and the amount of sunshine during the preceding day had been 0·4 hour.

This example will suffice to show how much information can be conveyed in a small space—or rather in a few figures—by the use of carefully drawn up codes. The use of such codes is the basis of all collection and interchange of meteorological information, and the codes now in use have been accepted for international exchange by all the meteorological services of the world.

THE USES OF THESE OBSERVATIONS

The observations which have been very briefly outlined above form the raw material on which the weather forecaster bases the charts of the weather from which he deduces the forecast for the coming period of 24 hours or so. Some explanation of the process of using the observations for the purpose of forecasting will be given in a later chapter. But it must not be supposed that the forecasting of the weather is the be-all and end-all of meteorology. Observations such as have been described above also form the basis of that function of an official weather service which may be called the preservation of the national memory of the weather. It is, for example, no uncommon feature of cases in the law courts that a judicial finding hangs on the weather at a particular time. As an example we may quote a lawsuit in which a tobacconist sued his neighbour for damage to a case of cigarettes, alleged to be due to rain coming through a skylight which had been broken by the defendant's son. The defendant admitted that his son had broken the skylight, and all went well for the plaintiff until, to quote the words of a London evening paper, "a mild-mannered gentleman from the Meteorological Office" proved that it had not rained since the skylight was broken, and the case had to be abandoned.

Weather is a particularly important factor in law-suits involving damage or loss of life at sea, and the function of a meteorological service in such cases is to provide such facts as it has been able to collect.

Rainfall statistics, which in the British Isles are collected from a much closer network of stations than is used for forecasting, are of the greatest importance to

water engineers, and form the basis of all decisions relating to water schemes of all kinds.

The collection of so many records of weather at a central office is not without its occasional humours. A story is told of a clergyman who, one Monday morning, reported 5·9 inches of rainfall as having fallen at his station. Since no one else in his neighbourhood had reported any rain as having fallen, a letter was sent asking him to confirm his figures. In reply he sent a letter full of the most profuse apologies for having confused the rainfall with the offertory. The offertory had been 5*s*. 9*d*., and the rainfall 0·0.

CHAPTER III

RADIATION FROM THE SUN, THE AIR, THE EARTH, AND THE CLOUDS

LIGHT AND HEAT

WE are familiar with the idea that light and heat are radiated from any bright body, and that hot bodies, even when not glowing, send out heat. Light and heat are both forms of energy sent out from their source in straight lines. They are both forms of what are known as electromagnetic waves, similar in character to, though very different in wave-length from, the waves used for wireless transmission, but all having the same speed of transmission of 186,000 miles per second. Thus the wave-length of pure blue light is only about one six-hundred-thousandth of an inch, roughly one forty-thousand-millionth of the wave-length of 1500 metres used by the wireless station at Droitwich. The range of wave-length represented by the difference between these two extremes is about 32 octaves, or more than four times the range of an ordinary piano. The human eye is sensitive to only a small range of these waves, the range of rather less than an octave extending from blue light to red light.

The ordinary white light from the sun or the sky can be spread out into a coloured band by passing a beam of initially white light through a prism. The beam is spread out into a vertical band, if the prism is set with its edge horizontal. The band is blue at the top, red at

the bottom, and the colours pass by slow gradation through the range violet, blue, green, yellow, orange, and red. Most textbooks include a colour indigo between violet and blue, but it is open to doubt whether most human eyes are capable of appreciating such a colour. Lights of different colours differ only in their wave-lengths, the red rays having a wave-length nearly twice as great as that of blue rays. Differences of wave-length in rays of light are appreciated by the eye as differences of colour, just as differences of wave-length of waves of sound are appreciated by the ear as differences of pitch. The rays from the sun are not limited to the visible colours. Instruments have been devised for measuring the intensity of rays beyond the violet, known as the ultra-violet rays, and of those beyond the red, known as the infra-red rays.

Solid bodies differ somewhat in the amount of energy which they can radiate outward from unit area of their surface, at a given temperature. But it is generally accepted that, at ordinary temperatures, the earth's surface radiates nearly the maximum amount of energy which a solid body can radiate. It is necessary to distinguish between this radiation of energy and the radiation of energy by a wireless transmitter. The latter sends out waves which are restricted to a very narrow band centred about the assigned wave-length. Thus when Droitwich transmits on 1500 metres, the waves are all within a small fraction of a metre of 1500 metres. But the solid ground, or any other good radiator, sends out waves within a wide band, the shape of which is known from theoretical considerations and confirmed by observation. The curve in Fig. 2, with scale A, shows the amount of energy radiated in different wave-lengths by a full radiator at a temperature of 27° C.

(about 80° F.). The actual wave-lengths are very small, the peak of the curve coming at 1/100 millimetre, or about 1/2500 inch. At lower temperatures than 27° C. the curve of Fig. 2 is lower, and its peak is shifted to the right to longer waves, while at higher temperatures the

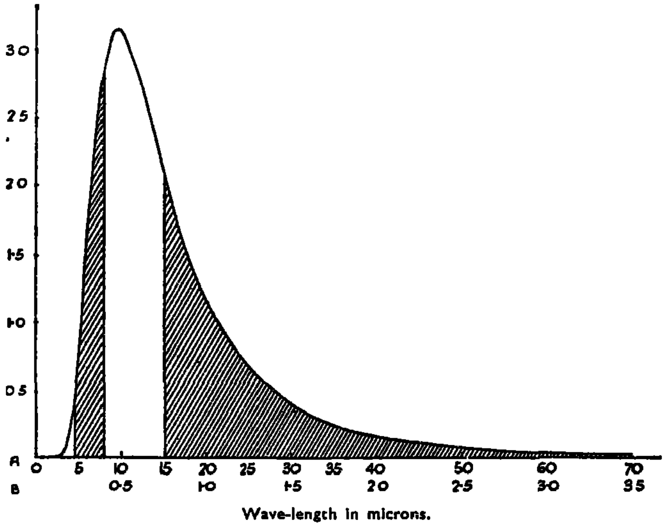


FIG. 2. CURVE SHOWING INTENSITY OF RADIATION.

With the scale A at the bottom, the curve shows the distribution of intensity of radiation from a body at temperature of 27° C. (80° F.). The hatched part of this curve shows the wave-lengths in which water vapour absorbs and radiates. The unhatched portions indicate wave-lengths of radiation to which water vapour is transparent. With scale B, the whole curve shows the distribution of radiation in sunlight. (1 micron = 1/1000 millimetre.)

peak is shifted to the left to smaller waves, and the curve is raised.

The colour of a radiating body will depend on the position of the peak in the curve of Fig. 2. As the body

gets hotter, this peak shifts towards shorter wave-lengths. Thus, if we set out to heat, say, a piece of iron, it will begin to send out heat-waves which will be felt on face or hand long before it begins to show any change of colour. As the iron gets hotter, the length of the waves it sends out will decrease, and a stage will eventually be reached when the waves will be short enough to be visible. These first visible rays will be a deep red, and they will first appear when the temperature of the iron is about 500° C., or about 970° F. Rays of wave-lengths belonging to the whole of the visible spectrum from red to blue will be radiated from the iron only when its temperature has reached about 1200° C. This agrees with normal experience that white hot is hotter than red hot. The following table gives a rough idea of the temperatures at which a glowing body such as a piece of iron will take different shades of colour.

Red just visible	500° C.
Dull red	700° C.
Bright red	900° C.
White	1200° C.

UNIVERSAL RADIATION

Any body, at whatever temperature it may be, sends out radiation of wave-lengths depending on the nature of the body and on its temperature. It will also absorb radiation from other bodies, turning it into heat. In passing, it may be added that when rays of light fall on any surface which does not reflect them, they are absorbed by the surface and turned into heat. We are, in fact, warmed by the light as well as by the heat of the sun; indeed, the difference between light and heat is appreciated by the human eye, but not by the rest of

the human body. Any solid body, whether in a room or in the open air, or any portion of the air in the atmosphere, must be regarded as receiving rays from every other body in its neighbourhood. Whether it will gain more energy from these innumerable beams of radiation than it sends out itself, will depend on the special nature of the bodies involved in the exchange. Some special cases will be considered later in this chapter.

THE SUN'S RAYS

With a clear sky, the light and heat from the sun pass through the lower atmosphere without having more than a very small fraction taken away by the air and converted into heat. When the rays reach the ground, a part is reflected upward from surfaces of water, of grass, leaves, etc., and the rest is absorbed by the surface of the earth, being used up in heating the surface and raising its temperature. In other words, the rays of the sun heat the earth, but do not heat the air. The earth's surface is continually sending out radiation to the sky, and so losing some of its heat. During the morning the income from the sun exceeds the loss from the earth's surface, and so the surface of the earth gets hotter, until a time is reached, between 2 and 3 p.m., when there is a balance between income and expenditure. The balance is usually only momentary, being succeeded by an excess of expenditure over income, and so the temperature falls for the remainder of the day and until about sunrise next morning.

HEATING THE AIR

Ordinary dry air does not send out or absorb any appreciable amount of radiation, but the water-vapour

mixed up with it does absorb and radiate energy in considerable amounts. For this reason the water-vapour must be regarded as the most important constituent of the atmosphere so far as radiation is concerned. Some of the radiation sent out by the earth's surface is absorbed and turned into heat by the water-vapour, which then shares out its gain with the dry air with which it is mixed.

The water-vapour in the atmosphere does not radiate or absorb within the whole range of the wave-lengths covered by the curve in Fig. 2, but only in the part of this range which is shown shaded in the diagram. Thus water-vapour is transparent to heat rays of the wave-lengths shown unshaded, these rays passing through it without absorption. Also, water-vapour does not radiate any energy in these wave-lengths. This is a universal rule, not only for water-vapour, but also for all other solids, liquids, or gases—that they radiate only in those wave-lengths in which they absorb. If, then, the air above the ground were all at the same temperature as the ground, it would send down to the ground less radiated energy than the ground sends up to the air, and on balance there would be a net loss from the ground, due to the uncompensated radiation from the ground in the bands to which water-vapour is transparent. In practice we find that usually the ground is warmer than the air at a short distance above it, and so the surface of the ground sends out more heat than it gains from the air even in the shaded bands of Fig. 2. Thus on a clear night the ground must lose heat by radiation upward, and so must cool steadily through the night. The drier the air, the less heat will it radiate downward, and the greater the net loss of heat from the ground.

The air above the ground cools in sympathy with the

ground, partly as a result of the decrease in the amount of heat radiated up from the ground and absorbed by the water-vapour in the air, and partly as a result of the slow churning of the air by the winds, which mixes the cold surface air with the air above it.

We have considered what happens when the only interchange of heat is by radiation from the ground and the air above it. Our conclusions are therefore to be applied solely to night-time. During the day, the radiation from the sun will be sufficient to make good the loss of heat from the ground by the exchanges between the ground and the air alone, with the result that during a great part of the day the ground is heated and its temperature rises.

By day the air in contact with the ground takes heat from the ground, and the heat so gained is carried upward through the air as a result of the churning process always present in the lower atmosphere. The result is that the temperature of the air up to some hundreds of feet above the earth's surface changes in sympathy with the change of temperature of the surface. Even on a still day, when there is no wind to churn up the lower atmosphere, there is a continuous ascent of columns of hot air from the ground, much like the little columns of air which rise from the so-called hot-water radiator. Incidentally it may be noted that the hot-water radiator heats a room much more by this process, known as convection or the ascent of hot air upwards, than by the radiation of heat. The currents of air rising from such a radiator carry with them small particles of dust, and, if allowed to rise along the wall, will in time leave a black mark on the wall, above and behind the radiator, as a direct proof of how the latter works.

It is important to realize the fact which has been stated

already in several different forms—that it is the ground, and not the sun, which warms the air by day, and cools it by night. The temperature of the air in a thermometer screen at a height of about 5 feet above the ground follows the same general trend as the temperature of the ground, though with a smaller range of variation from day to night. On a clear day it will attain its highest value at 2 to 3 p.m., and on a clear night will fall steadily until near sunrise. A record for a clear day followed by a clear night, at a station in southern England, is shown

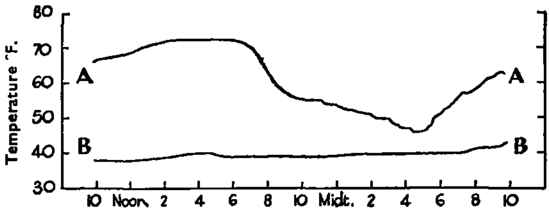


FIG. 3. DAILY VARIATIONS OF TEMPERATURE ON CLEAR AND CLOUDY DAYS.

AA : clear day followed by clear night.
BB : cloudy day followed by cloudy night.

in Fig. 3. The shape of the curve from sunset to sunrise is typical, with a very rapid drop just after sunset, and a slower but still steady fall until about sunrise.

The temperature of the air is what is often called the shade-temperature. The " temperature in the sun " is an expression often used, but is one which has no specific meaning. The temperature of any body placed in the sun will depend very largely on the nature and colour of the body. If, for example, we were to place in the sun a number of pieces of iron all of the same shape, but of different colours—say white, green, and black—the black piece would become hottest in the sun, the green

piece would be the next hottest, while the white piece would be the least hot. The same is, of course, true of clothing, white clothes being cooler than black in warm weather. Everyone is familiar with the fact as stated for clothing, but it is frequently overlooked that the same is true of any substance which absorbs the sun's rays.

THE EFFECTS OF CLOUDS ON THE AIR TEMPERATURE

When the sky is covered with cloud, about four-fifths of the radiation coming in from the sun is reflected from the top of the cloud sheet and sent back out into space. The rays which escape reflexion back outward pass through the cloud, being reflected to and fro between the droplets in the cloud, finally getting through to the bottom of the cloud and then travelling down to the earth's surface. The higher the sun the greater the proportion of the sun's rays which succeed in getting through the cloud, though, if the layer of cloud is very thick, only a very small proportion of the rays will get through even at noon.

A sheet of cloud will send out radiation in the whole range of wave-lengths of the curve in Fig. 2, except that the curve has to be slightly modified to the temperature of the cloud. As this temperature is usually lower than that of the ground, the cloud sends out less radiation than the ground, which therefore loses a little heat on balance. This loss from the ground—the difference between the expenditure and income of the ground—is roughly proportional to the height of the cloud. It is much less than the net loss from the ground on clear nights, since the cloud radiates to the ground waves which the water-vapour in the air cannot produce, the waves in the unshaded parts of Fig. 2. The result is that on a cloudy night the temperature of the ground

falls only very slowly, remaining practically unchanged all night when the sky is covered with thick low cloud. By day the amount of sunshine which gets through a cloud sheet down to the ground offsets, in part if not wholly, the net loss which the ground sustains in its interchanges with the air above it.

To put the matter in a few words, a sheet of cloud acts as a blanket, keeping out the heat of the sun by day, and keeping in the heat of the earth at night. The effect may be judged by a comparison of the two curves in Fig. 3, the one, AA, for a clear day followed by a clear night, the other, BB, for a cloudy day followed by a cloudy night. With very thick low cloud, the temperature will remain practically constant during day and night, unless a change in wind direction brings in air from a different region.

CONDITIONS FAVOURABLE FOR NIGHT FROST

We have already seen that the ground will cool most rapidly when the sky is clear. The cooling is further increased when the air is dry, containing little water-vapour which can hinder the outward flow of the radiation from the ground, and can itself send out radiation which is absorbed by the ground, and so helps to check its fall of temperature. The conditions which are most favourable for the occurrence of night frost are therefore a clear sky and relatively dry air. In winter or spring, at times when even the day temperature of the ground is low, whether there will be night frost or not will depend, on many occasions, on whether the sky is cloudless or not. Cloud clears away very frequently at or near sunset, and the result of this clearing may be a sharp night frost.

The extent to which the temperature falls at night depends on the nature of the ground, being greatest for

dry or sandy soils, and less for wet, and especially for water-logged soils. It is greatest on quiet clear nights when the ground is covered with snow, since snow conducts heat very slowly upward from the ground. In such conditions, the surface of the snow becomes very cold, while at the same time the snow acts as a protection to the ground beneath it, plants covered with snow escaping frost when the surface of the snow is well below freezing point.

So great is the damage to crops produced by spring frosts, that in many countries it is becoming a common practice to take special steps to protect orchard crops against hard night frost. In the United States cranberry crops are frequently protected by the simple device of flooding the bogs in which they grow. The fall of temperature over the flooded area is much less than over the unflooded area.

Other orchard crops are protected by the installation of oil-burners, in a network with a distance of 10 yards between the burners. These burners are arranged to burn with a bright glow, and it is the actual heating effect of the burners in keeping up the temperature of the layers of air in contact with the trees which affords the protection. Earlier attempts to protect crops from frost were made with burners which burned with a smoky flame, and so laid a cloud of smoke over the orchard; but this method was not found very effective, and had the additional disadvantage that the smoke spoiled the crop. All recent efforts at frost protection in the United States, Canada, India, and England have been made with clear-burning oil-burners. The cost of maintaining the burners is low, once the initial cost of installation has been met. For economic running of the method, the weather forecasts should be regularly studied,

and some type of instrument should be installed to give an alarm when the temperature falls below 35°, so that the burners can then be lighted. In this way the consumption of oil is reduced to a minimum.

In California and British Columbia it has been found that a whole crop of fruit may be destroyed by even an hour's frost during the early spring. The lighting of oil-burners has been found capable of raising the temperature in the orchards as much as 10°, obviating the danger of frost damage at a cost far below the value of the crop so protected.

THE DIFFERENCE BETWEEN OCEAN AND CONTINENT

It was not emphasized above that the sun's beams which reach the surface of the earth are absorbed by a very thin layer of the ground. The heat thus added to the solid surface is slowly distributed through a deeper, but still relatively thin, layer, by conduction, just as heat is slowly conducted from one end of a poker to the other. The net result is that all the absorbed energy is used up in heating relatively little depth of ground, and so the change of temperature which it brings about is great. But when the sun's beams fall on the surface of the sea, the result is very different. When the rays fall obliquely on the sea surface, as when the sun is low, they are almost entirely reflected. As the sun gets higher, the fraction reflected is diminished, but the rays penetrate to a very considerable depth. That this is so is a familiar fact to anyone who has stood on a bridge and seen the pebbles at the bottom of a stream. It will therefore be readily accepted that the sun's rays penetrate to a considerable depth in the sea before they are completely absorbed, and so they are used up in heating a considerable depth of water. Since the available heat is so widely

after its discoverer, Professor E. V. Appleton; and there are two intermediate layers at about 80 and 110 miles. Wireless signals travel in straight lines, just as light does, and a signal from London could not reach New York in a straight line without passing through the sea for the greater part of the journey. The wireless signal which succeeds in getting from London to New York does not, however, travel in a straight line through the waters of the Atlantic, but through the air, being reflected downward as by a mirror by one or other of the layers we have just mentioned.

We shall not dwell on the details of the methods devised by Appleton and others to investigate the conditions in these layers. The methods depend on the determination of the critical wave-length which fails to be reflected downward, and passes out through the layers. The results so far obtained point definitely to there being very little difference in air-density, and therefore in temperature, between summer and winter at 100 kilometres. But in the upper layer the differences between summer and winter densities are so marked that it is possible to explain them only by the assumption that on a summer day the temperature at 300 kilometres is at least over 900° C. (say 1600° F.).

REFRACTION AND MIRAGE

When a ray of light passes through a medium which has everywhere the same density, it travels along a straight line. If the density of the medium varies from place to place, the path is bent where it passes across a boundary at which the density changes. If the changes of density are slow and continuous, instead of being abrupt, the path of the ray is curved smoothly and not

abruptly bent. In the atmosphere, in the average conditions in which the density of the air steadily decreases upward, the result causes the slope of any ray of light which passes obliquely through the air to become steeper as it comes nearer to the ground, or to become less steep as it gets farther from the ground. In Fig. 4 an observer situated at a point A on the earth's surface will see a star S when he looks along the direction AB, since the ray which comes to him from the star has followed the curved path SA shown in the diagram. He therefore

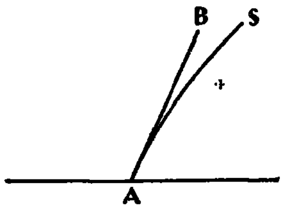


FIG. 4. HOW THE AIR SHIFTS THE APPARENT POSITION OF A STAR.

over-estimates the height of the star above the horizon. In normal conditions he can correct his measure of the elevation of the star above the horizon by the use of tables of the necessary correction. A similar error crops up in surveying, and is usually corrected on the assumption that the density decreases with height at a standard rate.

The direction in which rays of light are bent will obviously be reversed when the density of the air increases with height above the ground. Now, it can be shown that the density will increase with height above the ground if the rate of decrease of temperature upward is greater than $3\frac{1}{2}°$ C. for every 100 metres, or

say, more than 19° F. for every 1000 feet. But temperature falls off more rapidly than this on any sunny afternoon, particularly above sandy deserts or above macadam roads. In such cases, the rays of light are bent upward, those rays being most bent which pass through the region of upward-increasing density in a nearly horizontal direction. The effect of such bending of rays upward is seen almost daily by the motorist who travels along a macadam road, particularly on a stretch of road which has a gentle upward slope in front of the motorist, and a downward slope beyond that, so that the road is apparently bounded by a sky-line. In places in front of him, the motorist will see what appear to be

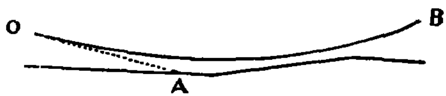


FIG. 5. MIRAGE ON A ROAD.

patches of water, which, however, disappear when he approaches them. What happens is that he views a part of the road over which the density of the air increases upward along a line such as OA in Fig. 5, where O represents the motorist's eye. But the ray of light which reaches his eye along the direction OA is a ray which has travelled along the path OB, and what he appears to see projected on the road is actually a small patch of the sky at B. As he approaches the spot at which the water appeared to be, he looks at it at an oblique angle, which does not allow any ray from the sky to reach his eye.

Over the desert, where the heating of the surface air is intense, the same effect is to be noted. Distant trees or grass may acquire a false air of nearness, just as on

macadam roads water may appear to the eye where actually there is none. There was an occasion in April 1917 when fighting between British and Turkish troops in Mesopotamia had to be abandoned for a time on account of a mirage which made it impossible for either force to see its opponents.

THE TRAVEL OF SOUND IN AIR

In still air, sound travels in a manner which in some ways is in strong contrast to that of light. The way in which a ray of sound will be bent in air depends not on the changes of density of the air, but on the changes of temperature. If the temperature decreases with height above the ground, a ray of sound will travel along a path which curves upward, becoming steeper the higher it gets in the atmosphere. Its path will curve round in the opposite direction to the line AS in Fig. 4, which represents the path of a ray of light in normal atmospheric conditions.

Any loud sound, such as that of the explosion of the projectile from a big gun, is audible within a distance of from 20 to 30 miles from the place of the explosion. Beyond this distance there is a zone in which the sound is inaudible, all the sound having been bent upward before it could reach so great a distance from its source. But at still greater distances—say from 70 to 80 miles from the source—the sound is again audible, because rays which have been bent upward from the ground eventually reach a level, at about 50 kilometres or so above the ground, at which the temperature increases with height so rapidly that the ray is again curved back downward to the ground. The existence of the outer zone, within which sounds from big explo-

sions are audible, although they are inaudible within an inner zone, affords a confirmation that the temperature increases with height in some higher layers of the atmosphere. This is the only way in which the observed facts can be satisfactorily explained.

There is one further aspect of the travel of sound which is worthy of mention at this point. We have considered above what happens in a still atmosphere—or, in other words, we have left out of consideration the effect of wind. This effect can be summed up in a few words, as it is an observed fact that the wind always increases with height in the lower layers of the atmosphere. A sound travelling down-wind is bent downward to the ground, and is therefore much more audible to anyone situated down-wind than it would be in the absence of wind, since the upward increase of wind-speed bends down to the ground rays which would otherwise have been lost by being bent upward by the normal temperature distribution. The effect is to produce a concentration of sound down-wind. But up-wind the contrary effect is brought about, the increase of wind with height sending the sound upward still more than the temperature distribution alone would have done. As a result, sound is more audible down-wind, and less audible up-wind, than it would be in still air.

CHAPTER V

WATER-VAPOUR IN THE ATMOSPHERE; RAIN, HAIL, AND SNOW

SATURATION OF AIR BY WATER-VAPOUR

THE amount of water-vapour in the atmosphere can be readily estimated by means of tables when the readings of the wet- and dry-bulb thermometers have been obtained. The warmer the air, the more water-vapour it can hold when saturated (see p. 10). But there is a peculiarity in the definition of *saturation* to which we must now make reference. If a mass of air is in contact with a flat surface of water, it becomes saturated when in a given time as many molecules of water-vapour go from the air into the water as from the water into the air. In general, when we speak of saturation, we mean saturation defined in this way. But even when air is saturated, in accordance with this definition, it can still take up water in the form of vapour, if the liquid water is presented to it in a sufficiently finely divided form. The air would then be *supersaturated*; it would contain more vapour than would be possible were it in contact with a flat surface of water. If the only liquid water on which the vapour can condense is in the form of small drops, then the air will be supersaturated, unless the water is a solution of certain salts which tend to produce a contrary action, and attract the water molecules.

Air over a flat surface of ice will take up less water-

vapour than air over a flat surface of water at the same temperature.

The average amount of water-vapour in the air does not change very much in the course of the day. The temperature, and consequently the maximum amount of water-vapour which the air could hold if saturated, is highest during the afternoon. So, with a given amount of water-vapour, the air will be farthest from saturation in the afternoon, and most nearly saturated at night, when the temperature is lowest. In general, we may say that the relative humidity of the air varies in the course of the day in the opposite sense to the temperature. In places where the air appears to be dry during the day, it is possible for it to be saturated at night. This has quite an important bearing on the life of plants, which can take water from the atmosphere when the latter is nearly saturated.

THE DENSITY OF DAMP AIR

When water evaporates into the atmosphere, the molecules of water-vapour are not simply added to the air which was originally present in, say, any cubic foot. Rather should we regard the water-vapour molecules as replacing an equal number of air molecules which they elbow out of their way. Thus, if we compare a cubic foot of dry air with a cubic foot of damp air at the same total pressure, we may say that the difference between the two consists in the fact that in the second case some of the molecules of dry air have been replaced by lighter molecules of water-vapour. Since the weight of a molecule of water-vapour is less than the average weight of a molecule of dry air, it follows that damp

air is lighter than dry air at the same temperature and total pressure.

EVAPORATION OF WATER INTO THE ATMOSPHERE

Water is evaporated, or turned into water-vapour and mixed with the atmosphere, at the surface of any sheet of water, over the sea, over rivers and other inland waters, and even over the land, where a considerable amount of water is evaporated by day from the surface of vegetation. The energy to do the work of tearing the molecules of water apart so as to form water-vapour is provided by the rays of the sun in the normal course of evaporation on a large scale. But this energy may in some cases be taken from the air, or even from the remaining water. The fact that the evaporation of water demands the supply from some source or other of the necessary latent heat to turn the liquid into vapour has some very important bearings on life in general. We have already considered one example of the effect of this evaporation, in the case of the ordinary wet-bulb thermometer. The bulb of the thermometer is wetted by its coat of muslin, and the evaporation of the water from the muslin cools the thermometer, so that it always reads lower than the dry-bulb thermometer when the air is sufficiently dry to produce any evaporation from the muslin. In this case the latent heat required to evaporate the water is actually taken from the air which passes the bulb, so cooling this air, and this in turn cools the bulb.

There is a well-known, though seldom stated, fact, that when air is cooled by the evaporation of water into it, the wet-bulb temperature remains the same during the whole process. This fact was first established by

Dr. C. W. B. Normand, now Director-General of Indian Observatories. An interesting example of this fact is afforded by the tatties, or water-soaked curtains, hung over open doors in India, to cool the air entering. The air which passes through the wet curtain is cooled by the evaporation of water from the curtain, but the wet-bulb temperature inside the curtain is the same as that outside.

When the process of cooling air by evaporation of water into it has lowered the ordinary or dry-bulb temperature until it is equal to the wet-bulb temperature, the air is saturated. Its temperature will then be equal to the original wet-bulb temperature, since the wet-bulb temperature remains unchanged through the whole process. Since the air is now saturated, it is not possible to evaporate any more water into it, so it cannot be cooled any further by evaporation. To put this into other words, a mass of air cannot be cooled to a temperature lower than its original wet-bulb temperature by evaporating water into it. In this way we gather an impression that the wet-bulb thermometer is not a mere artificiality, invented to enable the meteorologist to calculate the relative humidity of the air, but that it has a physical meaning of its own. If we propose to cool any specimen of air by evaporating water into it, we can tell beforehand how effective the process will be, by observing the temperature of a wet-bulb thermometer placed in our specimen of air. In thunderstorms the air near the ground is often noticeably cooled by the evaporation of falling rain. If the rain lasts long enough, the air will be cooled until its temperature is about equal to the wet-bulb temperature before the rain started.

An interesting example of the energy required to turn

water into water-vapour being supplied by the cooling of the water left behind, is the method, commonly used in India, of cooling drinking-water by placing it in a porous pot, exposed to the hot breeze, but sheltered from the direct rays of the sun. The water which passes out through the pores of the pot is evaporated, and the pot and the remaining water are cooled. The method has many household applications, useful to the housewife who has no refrigerator at her disposal. Meat or butter placed in a plate containing a shallow layer of water, and covered by a piece of muslin which dips into the water all round the plate, is kept cool by the evaporation of the water from the muslin. In temperatures up to about 85° F., butter can be kept cool and firm by this simple method, which demands no attention beyond seeing that the water is renewed when its level is low.

CONDENSATION OF WATER-VAPOUR

Condensation is the opposite of evaporation, and is the conversion of water-vapour into liquid water. In the atmosphere the condensation of water into drops takes place, not by the molecules of water-vapour collecting together, but by the collection of the molecules of water-vapour on a particle of dust of a particular type. Such fine dust as can be collected from a coal-cellar, or from a carpet, will not in general act in this way as the foundation of a water-drop. The dust particles which can act in this way, and to which have been given the name of *nuclei* (singular *nucleus*) *of condensation*, are mostly little particles of common salt from the sea, or of sulphur products from chimneys. There is always a sufficient supply of nuclei in the atmosphere to act as foundations for the water-drops in clouds or rain.

Before the water-vapour in the atmosphere can condense on the nuclei, the air must be saturated or nearly saturated. This may be brought about in three ways:

(*a*) Damp air mixed with another mass of damp air at a different temperature will in certain circumstances give a mixture which is saturated, so that condensation can take place. Water fog at sea is often formed in this way.

(*b*) When air passes over a very cold surface of land or sea, it may be cooled so much that the water-vapour it contains initially is more than sufficient to saturate it. Some of the excess of water-vapour will then condense as fog particles. This is the process which accounts for the thick fogs which form over the Great Banks of Newfoundland, where a current of warm damp air from the Gulf of Mexico blows over the cold current of sea-water (the Labrador Current) which flows down the eastern coast of Canada. The same process accounts for the uncomfortable conditions which often result when a spell of cold weather, in which the ground and walls of buildings have become cold, finally breaks down with the coming of a warm damp wind. Air which gets into houses is cooled by contact with the walls, on which it deposits its excess of water.

(*c*) When a mass of damp air rises through the atmosphere, it expands and cools, and eventually reaches a stage at which it is just saturated. Any further ascent will cause some of the water-vapour to condense as cloud droplets, and if the process is continued still further, the drops will grow in size by further condensation, until they become raindrops and fall to the ground.

THE DIFFERENCE BETWEEN CLOUD AND RAIN

The obvious distinction between cloud and rain is that cloud floats, while rain falls. But this obvious distinction is not a true one, the fact being that cloud-drops fall too. Any small drop of water will fall, but the rate at which it will fall depends on its size, the larger drops falling more rapidly than the smaller ones. The size of cloud droplets varies within a wide range, though averaging about eight ten-thousandths of an inch in diameter. Drops of this size fall through a distance of about 150 feet in an hour, and it would require only a very gentle upward current to keep them from falling at all. Raindrops also vary in size; the drops in light drizzle have a diameter of about eight-thousandths of an inch, and fall at a rate of about 2¼ feet per second; the drops in heavy rain average about 1/16 inch in diameter, and fall about 17 feet in a second.

SOME FEATURES OF CLOUD FORMATION

The cumulus or wool-pack cloud of the sunny afternoon is formed by the ascent of warm damp air, as we have suggested earlier, and the cloud may be regarded as evidence of the existence of the upward current. But there is one feature of the cloud, its clear-cut base, which merits further discussion. The cumulus cloud never shows a base which fades away gradually into blue sky, but has a hard edge at which bright cloud abuts on blue sky. The reason for this can be put into a few words, though it is not of necessity easy to grasp. As the damp air rises in an upward current, it presently reaches a stage at which it is just saturated. Further ascent will cause some condensation on the nuclei which are always present, but the small drops do not at first

grow rapidly, since, as stated on p. 56, water in the form of small drops tends to evaporate unless the air is very much supersaturated. With further ascent some condensation will take place, and as the drops grow, the amount of supersaturation which can exist decreases very rapidly. The growth of the drops becomes much more rapid, and the change from invisible drops to visible drops takes place in quite a small range of height—so small, in fact, that it cannot be appreciated by the human eye. The result is to give the cloud base a clear-cut outline.

HOW RAIN FORMS

Rain is formed by the ascent of damp air. When a mass of damp but unsaturated air rises from the ground, its temperature falls at first at the rate of about $5\frac{1}{2}°$ F. for every 1000 feet of ascent. But a stage comes at which the amount of water-vapour present is just sufficient to saturate it. Any further ascent will cause condensation of water-vapour, in the form of rain or snow. When the water-vapour condenses, the latent heat originally used up in evaporating it is liberated, and is used up in checking the rate at which the temperature of the rising air falls with ascent. The result is that when saturated air rises through the atmosphere its temperature does not fall at the same rate as that of rising dry air. At the ground, and at temperatures of about 60° F., this rate of fall of temperature is only about 3° for every 1000 feet of ascent. If the temperature of the surrounding air falls off with height more rapidly than about 3° F. for every 1000 feet, damp air will rise freely through the atmosphere, and rain can easily form. When it is possible to foresee that the

limit will be surpassed, it is usually safe to predict rain, and if the limit is greatly surpassed, thunderstorms may occur.

This is the only way in which rain in any quantity can be formed—by the ascent of damp air. The ascent of the damp air may be produced in a variety of ways. When a cold current of air from the north passes over warmer seas on its way southward, it is warmed from below, and the result may be to produce a variation of temperature with height greater than the limit of stability. There will then be a tendency for the warm air at the surface to rise, and, if it rises sufficiently high, rain or snow will form.

Rain may also be caused by the forced ascent of air over high ground. If a warm south-westerly wind flows against a range of hills, it will be forced to rise over the hills, and in so doing will yield up much of its water-vapour as rain or snow. Some of the heaviest rainfalls in the world are caused in this way, notably the rainfall of the south-west monsoon of India, the heavy rains of parts of the western coasts of America, and even the heavy rains of the hilly parts of the British Isles. If a current of air rises over a range of hills, and in so doing loses most of its moisture, as it inevitably must if it is forced to rise very high, it will descend the other side of the mountains as a dry wind. In descending it will be warmed up at the rate of about $5\frac{1}{2}°$ F. for every 1000 feet of descent, as a result of compression when it comes down into levels of higher pressure. It will thus reach the low ground on the lee side of the high ground as a warm and dry wind. This effect is very noticeable in mountainous regions in all parts of the world.

There is a third way in which warm air may be forced to ascend, and to yield up its water-vapour as rain or

snow. If a warm current of air clashes against the flank of a cold current, the warm air will rise over the cold air just as it would over the flank of a hill. It is in this way that most of the rain associated with the depressions which pass across middle latitudes is formed. We shall see later that the depression is in the main to be regarded as a battle-field where warm and cold currents of air clash, and it is along the line at which the contending currents clash that most of the rain in a depression falls.

RAIN, SNOW, AND HAIL

When the condensation of water-vapour from a current of ascending damp air takes place at temperatures above freezing point, the precipitation is in the form of rain; but if the rising air becomes saturated only at levels above those at which the temperature has fallen to the freezing point, the precipitation takes the form of snow. This does not always mean that snow will fall to the ground, since snow crystals formed up in the free air and falling through air whose temperature is well above freezing point, will melt on the way down. Snow can reach the ground only when the temperature even at the ground is down to freezing point, or at most a degree or two above it.

The crystal of snow is one of the deepest mysteries of the atmosphere. It has six arms, all alike; but no two crystals are ever alike. Several amateurs have made a life hobby of the photography of snow crystals, but their photographs have never shown duplicating of the form of a crystal. There is no essential difficulty in the photography of snow. The crystals can be caught on a blackboard, or on a piece of black velvet, and photographed directly, without any elaborate precautions.

Some examples of photo-micrographs of snow crystals are shown in Fig. 6.

The formation of hail demands very special conditions. When water-drops are formed in a rising current of air, and are carried up beyond the level at which they are formed, they do not freeze immediately when they reach the level at which the temperature is down to the freezing point, but remain at first in the form of liquid water, though at a temperature below freezing point. They probably begin to freeze when their temperature falls below about $-10°$ C., or $14°$ F. The raindrop then freezes into a soft core of white ice. If it now falls downward, it will at first meet drops of water at a temperature below freezing point, and these drops will readily freeze on to the falling core. In freezing they trap some air within the ice, so that the coating which they form on the falling core will be of white ice. As the core, now covered by a coating of white ice, falls still farther, it reaches the level where the temperature is at freezing point, with its own temperature well below this limit. Water-vapour will condense on the ball of ice in the form of water, which freezes rapidly into clear ice. As a result of its journey, the hailstone—for such it now is—will have an inner core of soft ice, then a coating of white ice, and outside this a coating of clear ice. If the current in which the damp air was first carried up is intermittent, it may again carry up the hailstone into the region where it first caught its inner coating of white ice, and where it will in just the same way catch another coating of white ice. When a lull in the rising current allows the hailstone to fall, it will again take a coating of clear ice. The process may be repeated many times, each double journey leaving evidence in the form of a coating of white ice and a

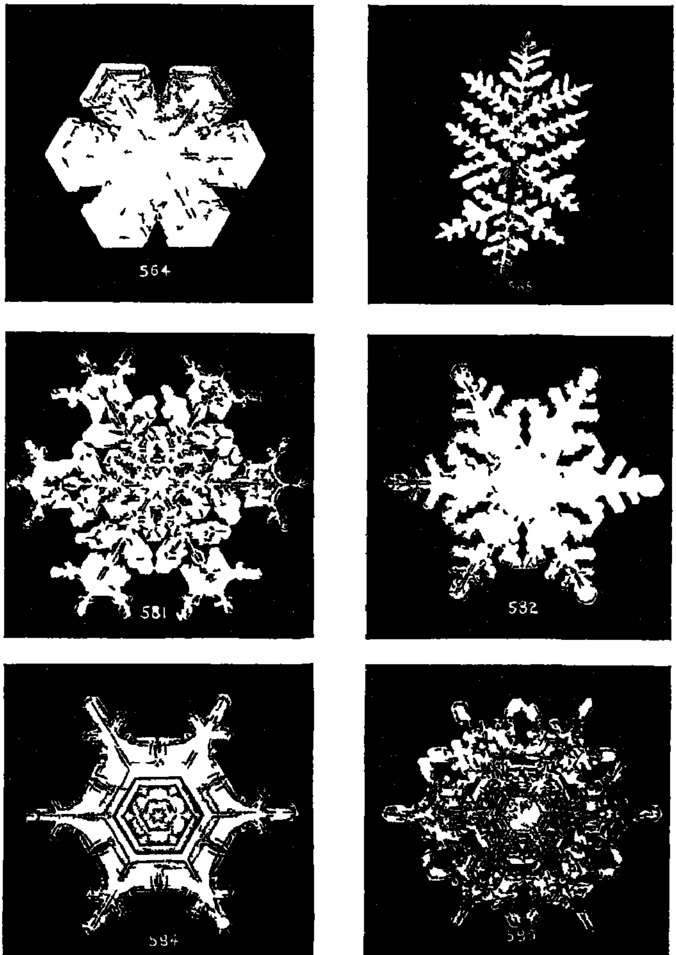


Fig 6 Snow Crystals

coating of clear ice outside it, while the hailstone grows in size and weight. The process cannot go on indefinitely, since eventually the hailstone becomes too big for the rising current to hold it up. It must then fall to the ground. Hailstones bear in their structure, which can easily be verified by cutting through the centre, evidence of their own past history, as well as of the upward currents in which they were formed.

Large hailstones can form only when there are violent ascending currents in the atmosphere, so that the stones shall not fall too rapidly. Further, the clouds must extend to a great height, at least to the level at which the temperature is down to $-20°$ C. ($-4°$ F.); and the base of the cloud must be below the level at which the temperature is at freezing point. These conditions occur most frequently in warm regions, where violent ascending currents occur most readily, and where the rising air reaches saturation at a temperature well above freezing point. In the British Isles these conditions are most strongly developed in summer, and it is therefore in summer thunderstorms that large hailstones are seen in the British Isles.

When the temperature of the ground is low, so that ascending currents are relatively slight and the temperature at the base of the cloud is not much above freezing point, the region in which the stone acquires its coating of clear ice is then of no great vertical extent, or may even be totally absent. The hailstones which then fall are small, consisting only of the soft white core such as forms the centre of the large hailstone. These small soft hailstones are known as *soft hail*. They are frequent in Europe in winter, when the base of the cloud is at or near freezing point. In the hills of India soft hail is also frequent at stations which are sufficiently high to be

above the level at which liquid water could exist. The ascending currents develop over the plains, carrying up water-drops which freeze into soft hail and fall, reaching the ground before they can attain a level at which they could acquire a coating of clear ice.

Some of the rain which falls in winter in the British Isles, as well as other places in middle latitudes, starts in the upper levels at which condensation takes place, as snow, and melts on the way down; and rain starting from high levels may in certain conditions be evaporated before it reaches the ground.

DEW, HOAR-FROST, AND RIME

When the ground or any solid surface exposed to the air cools below the temperature known as the dew-point, or the temperature at which the amount of water-vapour in the air would be sufficient to saturate it, there is a deposit of water on the surface. This water is known as dew. When the temperature at which condensation of the water-vapour out of the atmosphere takes place is below the freezing point, the deposit is in the form of the hoar-frost. The process is the same as the deposition of water on the cold walls of houses, to which reference was made on p. 61, or the dewing of a glass full of cold water in a warm room. It is a common idea that dew falls; but heavy dew forms only when the ground is damp, and water-vapour comes up from the soil into the surface layers of air. Heavy dew might, then, be more truly described as rising than as falling.

The deposits of rough white ice which grow out to windward of any exposed object when water fog and frost occur together, are known as *rime*, and should be

distinguished from hoar-frost. Hoar-frost is formed by the direct conversion of water-vapour into ice, while rime is formed by the freezing of the fog droplets which come into contact with cold objects. Rime can take the most extraordinary shapes, and on the leaves of trees it forms a delicate pattern of crystals.

HALOS AND CORONÆ

The corona, or system of coloured rings which show around the sun and moon when seen through sheets of thin cloud, can be formed only when the cloud consists of water-drops. Quite different from this is the halo, a narrow whitish ring round sun or moon, having a radius of 23°, and quite different in its message, since it indicates that the cloud is made of ice crystals.

There is also sometimes visible a halo of 46°, and a number of complicated arcs have been seen from time to time, and explained as halo phenomena. They are too complicated to permit of description in detail in the space at our disposal here.

RAINBOW

The rainbow is formed by the bending of rays of light in water-drops, the separation of the colours being due to the fact that different colours are bent to different extents. It is seen projected against a rain-cloud when the observer has his back to the sun, and its centre, the eye of the observer, and the centre of the sun are in one straight line. The radius of the primary, or brightest bow, subtends an angle of about 41° at the eye, while the radius of the secondary bow, which appears outside the brighter primary, subtends an angle of about 52° at

the eye of the observer. Sometimes a third bow appears outside the secondary bow.

It is usual to say that the colours in the primary rainbow are violet, blue, green, yellow, orange, and red, with the red on the outer side of the arc; while in the secondary bow the order of the colours is reversed. This is a much-idealized picture of the average rainbow, in which the six colours mentioned are seldom all recognizable. The widths and brightness of the bands of different colours may vary within wide limits, and some of the colours may be absent. Also it is not uncommon to see bands of violet or pink inside the primary rainbow. What we may call the standard text-book rainbow occurs when the drops in the rain-cloud are about 1 millimetre in diameter. Smaller drops usually show little or no red, and white bands separating other colours occur when the drops of water are about 1/10 millimetre in diameter. The bow seen when the sun shines on fog is almost pure white, and is known as a *fog bow*. Here the drops of water are much smaller than in any rain-cloud.

Rainbows can also be seen by moonlight when other conditions are favourable; but the light is so faint that the eye cannot distinguish the colours, and the impression is gained of a silvery-white bow.

FIG 7 CIRRUS CLOUD

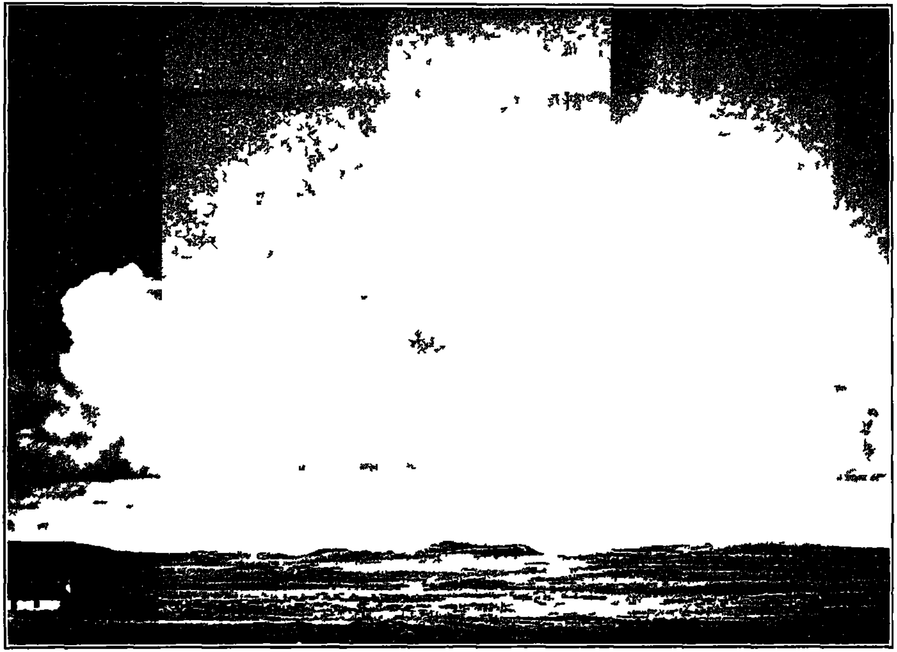


Fig 6 Cumulus Cloud

CHAPTER VI

CLOUDS AND THEIR CLASSIFICATION

THE varying structure of clouds can be described by means of four main types and the structures intermediate between them.

Cirrus, the highest cloud, has a feathery or fibrous appearance, as shown in Fig. 7. The cloud is a fairly typical example; but some variations from this exact appearance are to be seen in cirrus clouds from time to time. Cirrus is a cloud of ice crystals, being formed at levels at which the temperature is so low that liquid water cannot exist.

Stratus is a uniform sheet of cloud, with little or no structure, appearing much like a fog raised above the ground.

Cumulus, woolpack, or heap cloud, is the cloud of sunny afternoons, having a flat base and rounded top, sometimes appearing isolated, but frequently arrayed in long lines. A typical example of the latter is shown in Fig. 8.

Nimbus is a dense, shapeless mass of dark cloud, from which rain or snow is falling.

Between these four main types it is possible to have an almost infinite number of intermediate classes. Certain of these intermediate types have a sharply defined special form.

Cirro-Stratus is a thin, whitish sheet of cloud, which sometimes covers the whole sky; sometimes it has no

definite structure, but at other times it may look like a tangled web.

Cirro-Cumulus is a high cloud which is composed of small, irregular, globular cloudlets, which may be arranged either irregularly, or in roughly parallel lines. Sometimes the cloudlets form rows in two directions roughly perpendicular to one another, giving the appearance of two sets of undulations or waves at right angles. These clouds take their very peculiar form largely on account of the radiation of heat from the upper surface. The top of the cloud is cooled so much that it becomes unstable. The way in which this unstable layer moves may be simulated by pouring a little cheap gold paint into a shallow dish, to a depth of, say, a quarter of an inch. The evaporation of the volatile constituents of the gold paint cools the surface, and makes the liquid at the upper surface denser than the liquid below. The whole of the surface will appear to be divided into a large number of irregular polygons, inside each of which the liquid rises up at the centre, flows outward at the top, and descends along the outer margin.

Alto-Cumulus has the same general structure as Cirro-Cumulus, but the cloudlets are larger, and show definite shadows, while those of Cirro-Cumulus show only very slight shadows, or none. Fig. 9 shows a typical example of Alto-Cumulus.

Alto-Stratus is a dense sheet of cloud of a grey or grey-blue colour, generally showing little or no structure, but occasionally having an ill-defined fibrous appearance.

Strato-Cumulus is formed of dark heavy masses of cloud arranged irregularly, with interstices brighter than the main cloud, or of blue sky.

Cumulo-Nimbus is the thunder-cloud, which often takes the form of an anvil, capped by a fibrous top known as

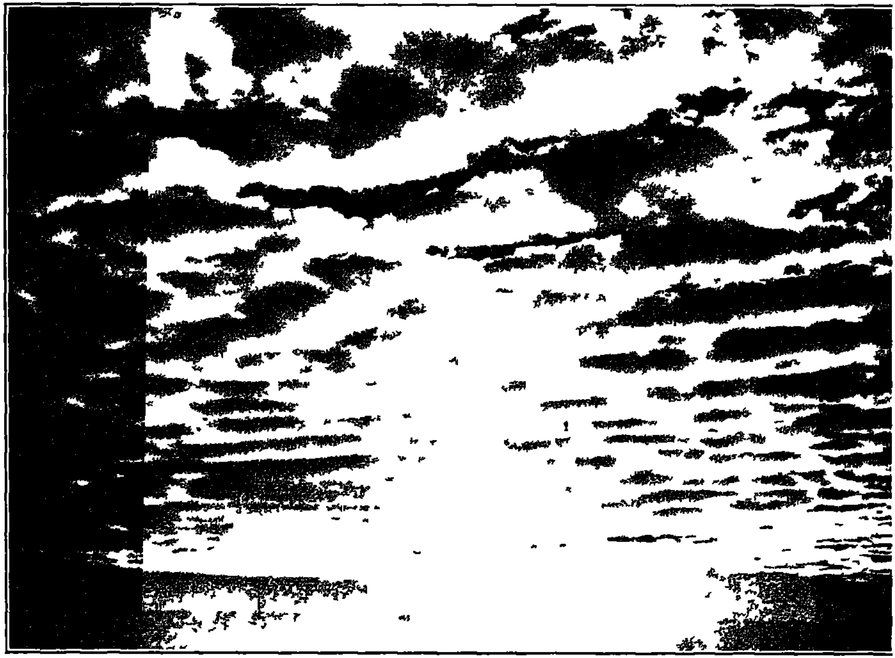


FIG 9. ALTO-CUMULUS CLOUD.

FIG. 10. CUMULO-NIMBUS OR THUNDER CLOUD

" false cirrus." The fibrous top is formed of ice crystals. Fig. 10 shows a well-developed thunder-cloud.

THE COLOUR OF CLOUD

Clouds vary from dazzling white through a variety of shades of grey to nearly black. A cloud of water-drops reflects about four-fifths of the sunlight falling upon it, and therefore when a cloud is so placed that the sunlight falling upon it can be reflected to the observer's eye, it appears dazzling white. When a cloud is of no great vertical extent, some of the sun's rays which are reflected from one drop to another contrive to pass through the cloud, and so reach the observer's eye. As it thickens, the amount of light reaching the observer's eye from the cloud is diminished. When the cloud is very thick, practically no rays from the sun get through it, though some rays scattered from other clouds or from the air may reach the cloud, and pass from it to the eye of the observer. There will always be some light of this kind coming from a cloud during the day, and so no cloud appears dead black. At most it can only appear a very dark grey, even in the least favourable circumstances, and with thinner clouds brighter greys appear in the scheme of cloud colours. When there are several layers of cloud, none completely covering the sky, a low cloud will appear most nearly black if it has other sheets of cloud above it. Any visible portion of higher cloud will appear in brighter grey than the lower cloud, and a portion of a still higher cloud visible through gaps in two layers will appear brighter than any part of the sky not so visible.

CHAPTER VII

THE WEATHER MAP AND THE WEATHER FORECAST

PLOTTING OBSERVATIONS ON A MAP

IN Chapter II we outlined the observations which are made at official meteorological stations, and referred briefly to the meaning of some of these observations. While the records so obtained form the basis of the discussion of climate, and constitute what we called the public memory of the weather, they have another and more immediate purpose, in that they form the basis of all weather forecasting. The first step in the process of forecasting is to plot the observations on a chart, an outline map of an area which is usually far more extensive than that for which the forecasts are to be made. Thus the British service uses as a working chart a map which covers most of Europe, and extends well out into the Atlantic, so that the weather over a wide region can be seen at a glance.

The method of plotting observations is simple. Alongside the dot which marks the position of a station is written the pressure in millibars to the first decimal place, the initial 9 or 10 being omitted, as no confusion is caused by this. Thus 994·6 mb. is written as 94·6, and 1024·3 mb. as 24·3. Under this is written the temperature, and under the temperature the Beaufort letters for the weather. The wind direction is indicated by an arrow ending at the station position, and the

force of the wind on the Beaufort scale is indicated by the number of barbs on the arrow. The tendency of the barometer, or the change in pressure during the last three hours, is written above the pressure. Thus the observations at Pembroke at 7 a.m. on July 1, 1935, given in detail on p. 22, would be shown as follows:

		wind	N by E force 5
-6		barometer	fallen 6 since 4 a.m.
15·1		barometer	1015·1
55		temperature	55
c	meaning	sky	cloudy

Beaufort letters indicating the weather since the last time of observation may be written below these symbols in red ink.

DRAWING THE ISOBARS

The next step is to draw lines on the chart through points at which the pressure is the same. These are much like contour lines on a map, and are drawn freehand, taking account of the observed pressures at the points of observation. The pressure lines, which are called *isobars*, are usually drawn for intervals of four millibars, at 992, 996, 1000, 1004, 1008, etc. If two adjacent stations had pressures of 1007·2 and 1009·6, the distance between the isobar of 1008 and the first station would be half as great as the distance between the isobar and the second station.

While some of the isobars pass across the map in a sinuous and often very irregular form, others are closed curves, enclosing centres of high pressure (anticyclone), or centres of low pressure (cyclone or depression). The

centres of high or low pressure move across the map, from one series of observations to another, and it is an important part of the work of the forecaster to predict the manner in which these centres will move during the interval for which he has to make the forecast. He requires also some method of detecting these centres while they are in an early stage of development, and, if possible, to foresee where the next centre will develop. If he can contrive by any method to foresee the form which the isobars will take 24 hours ahead, he is in a strong position, since the general features of the weather are associated in a special way with the form of the isobars, while the wind can be indicated with reasonable accuracy by the use of a law known as Buys Ballot's Law, after the Dutch meteorologist who first formulated it. This law states that in the northern hemisphere an observer who stands with his back to the wind will have lower pressure on his left than on his right, while in the southern hemisphere he will have higher pressure on his left. This means that the wind blows roughly along the isobars, keeping low pressure to the left in the northern hemisphere, and to the right in the southern hemisphere; but the surface winds tend to blow slightly across the isobars, from high pressure to low, at an angle of 20° to 30° with the isobars. Moreover, the winds are strongest where the isobars are crowded most closely together. This law is one of the most definite laws in the whole of meteorology, and it is of the greatest value, in that it enables the forecaster to foretell the wind as soon as he has been able to determine the way in which the depressions or anticyclones on the map will move.

THE DEPRESSION

The general details of the methods which the forecaster uses cannot be elaborated here, and all we can do is to give an outline of these methods. If, for example, the chart shows a depression, and the tendencies show that the pressure is falling most rapidly to north-east of the centre, and rising most rapidly to south-west of the centre, then the depression is moving to north-east. Perhaps we should say that in the last three hours the movement has been to north-east. However the use of this method involves the assumption that the depression will go on moving in the same direction. If depressions went on moving in the same direction during the whole of their existence, the problem of forecasting would be a much simpler one than it actually is. Unfortunately, this does not always happen, and from time to time depressions behave in the most unexpected ways, occasionally moving in paths as complicated as a figure of eight.

Depressions which come across the eastern North Atlantic, and reach the north-western parts of Europe, move as a rule in a direction between east and north-east; but the motion of individual depressions may differ widely from the average, and in practice it is necessary to consider each depression as a new problem, and to determine its motion from the observations plotted on the chart.

In Fig. 11 is shown a chart based on observations at 7 a.m. on April 1, 1927. There is a depression centred over Belgium, marked LOW on the chart. The isobars, which are drawn for intervals of two millibars, are most crowded on the south-western side of the depression, where we therefore find the strongest winds. The broken line extending from the centre out to the west

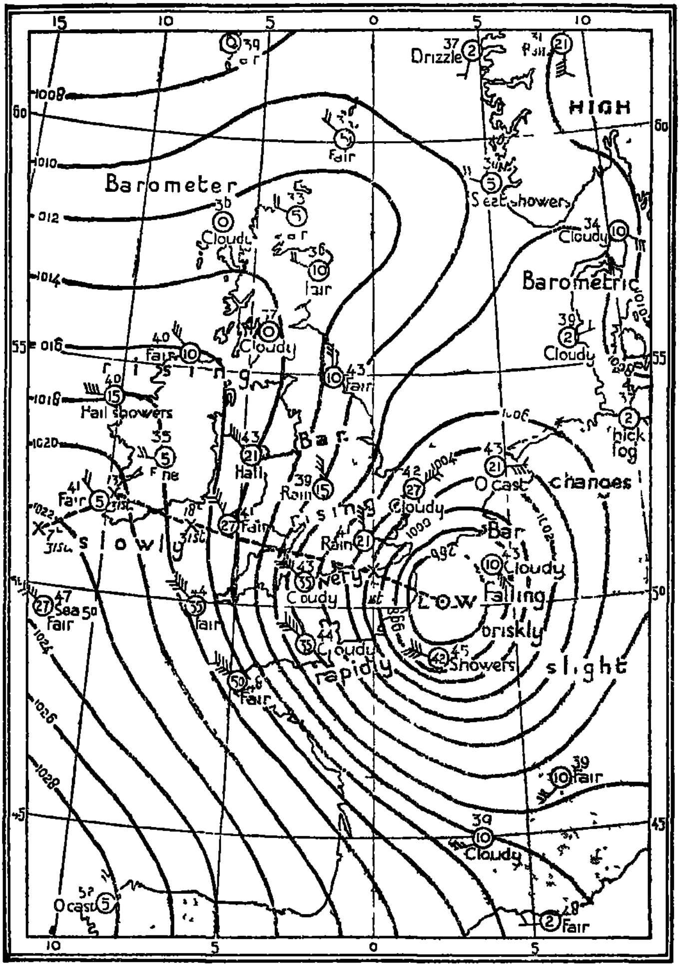


FIG. 11. DEPRESSION OF APRIL 1, 1927.

of Ireland shows the track followed by the centre since 7 a.m. on the preceding day. Crosses shown on the track indicate the position of the centre at 7 a.m., 1 p.m., and 6 p.m. on March 31, and at 1 a.m. on April 1. It is stated on the chart that the barometer was falling briskly in front, and rising rapidly to the rear, of the depression.

An intense small depression of this type has the

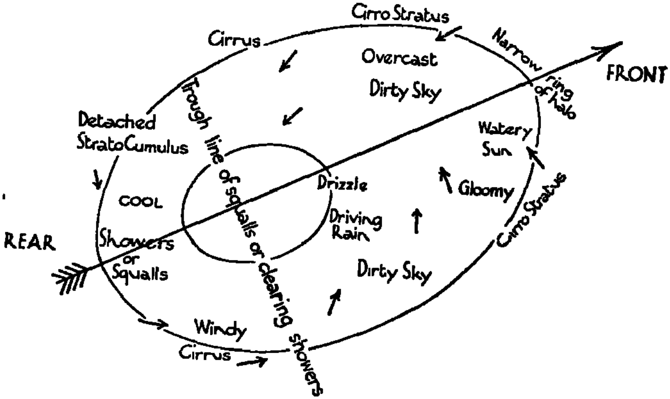


FIG. 12. WEATHER IN A DEPRESSION.

appearance of being a whirl of winds revolving counter-clockwise. The winds blow at a slight angle across the isobars, but in such a direction as to keep lower pressure on the left than on the right. This particular depression brought windy, cloudy weather, but relatively little rain. West of a line joining Brest to Pembroke the weather is mainly fair. The direction of motion of this depression is along the direction of the strongest winds, the W.N.W. winds blowing around the southern edge of the closed system of isobars.

The diagram of a typical depression shown in Fig. 12

shows the view of the structure of a depression which formed the working basis of the forecaster up to the end of 1918. This picture is due to Abercromby and Marriott. It was with this scheme of the relation of weather to pressure distribution that the forecaster worked.

NORWEGIAN SCHEME OF THE POLAR FRONT

During the war of 1914–18, the Norwegian meteorologists evolved a picture of the depression as the clashing of a warm current of air with a cold current, and so succeeded in unifying into one coherent scheme a number of ideas which had, at different times, been put forward by various meteorologists of different nationalities. They visualize the centre of the depression as being on the line separating the warm and the cold currents, so that the depression shown on the chart of surface conditions has a warm sector and a cold sector. The line of separation—or rather the battle-front—between the warm and cold currents is known as the polar front. We can study the polar front most readily by considering a typical depression, in which the contrast between the two currents is well marked. In Fig. 13 is shown the depression of October 22, 1932, at 7 a.m. The figures opposite each station, reading downward, are first the tendency (the fall of pressure in the last three hours, measured in half-millibars), the temperature, and the Beaufort letters for the weather at the time of observation. The pressure observations are omitted, the isobars showing these with sufficient detail for our purpose. The line passing from the Bay of Biscay to Holyhead, and then eastward across the North Sea, is the polar front. The temperatures are in the neighbourhood of 55° to south-east of the front, in the

warm sector, and about 45° on the other side of this line. There is also a definite change of wind direction in going across the front. The part of the front which

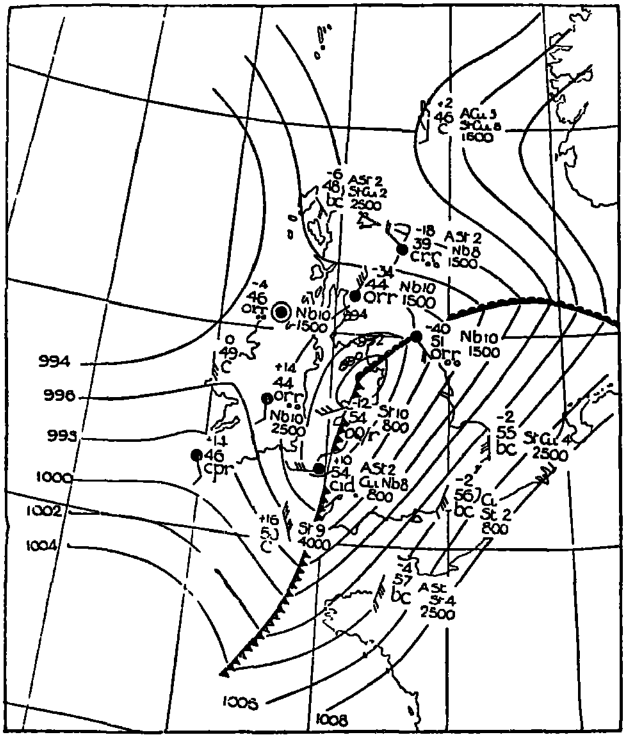


FIG. 13. DEPRESSION OF OCTOBER 22, 1932.

is decorated with pointed teeth, where the cold air in the rear of the depression impinges on the flank of the warmer current, is known as the *cold front*. Here the cold air pushes under the warm air, forcing it upward,

but doing so rather jerkily. The condensation of water-vapour produced by the ascent of the warm air produces rain, most of which falls down through the cold air to the ground. The rain therefore falls behind the cold front, in the cold air. Along the part of the front marked with rounded teeth, where the warm current attacks the flank of the cold current, and known as the *warm front*, the warm air flows up over the cold air. Here again the ascent of the warm air leads to the formation of rain, which falls through the cold air to the ground. The rain which falls at the warm front is the heaviest rain in the whole depression, and it usually continues for a much longer period than the rain which falls at the passage of the cold front.

On a chart showing a depression we should therefore expect to find a wide band of rain in advance of the warm front, the rain falling on that part of the surface of the ground which is in cold air. In the warm sector there is usually only intermittent rain, except at the tip of the tongue of warm air, where the rain may be very heavy and continuous.

Noticeable features of the chart in Fig. 13 are that at the polar front the isobars show rather an abrupt change in direction, and that in the warm sector they form a series of nearly parallel lines. It is found that the depression will move along the direction parallel to the isobars in the warm sector. This provides a rule which enables the forecaster to form a reliable idea as to the direction in which the centre of the depression will move, and may be regarded as a substitute for the use of tendencies as described earlier. The depression in Fig. 13 should be compared with the idealized depression of Fig. 14.

The depression shown in Fig. 13 shows a very clearly

defined polar front, and is well worth studying in some detail. The distribution of the temperatures, the areas

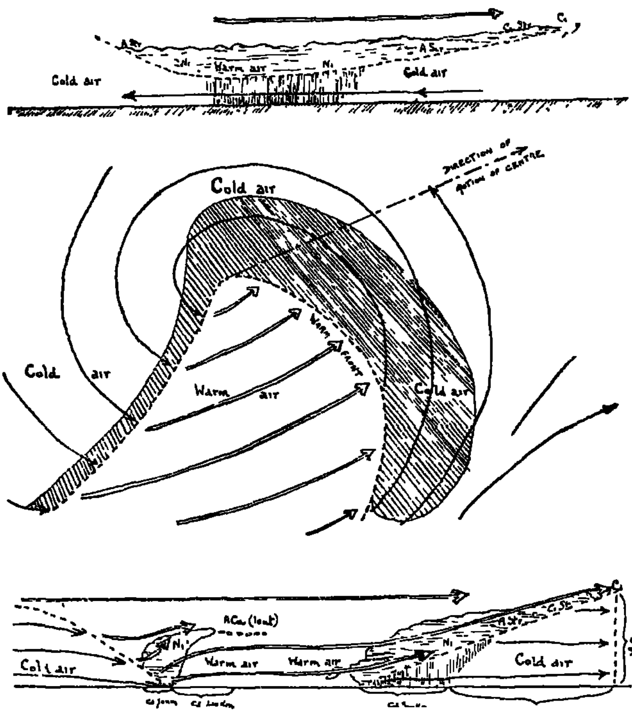


FIG. 14. NORWEGIAN SCHEME OF A DEPRESSION.

The centre diagram shows the wind circulation in a depression; the rain area is shown hatched. The upper diagram shows a vertical section through the depression north of the centre, and the lower a similar section south of the centre. Note that the cold air appears in the form of a wedge.

of the belts of rain, and the forms of the isobars, all agree with what we may call the text-book description

of the polar front depression. There are also some differences between the other properties of the warm and cold air which must be mentioned. In the warm air the visibility is usually poor, particularly if the air has come over land during a large part of its journey northward. If a mass of cold air has started far north, and after coming southward has swung round and approached from a southerly direction, it may appear as relatively warm air in which the visibility is still good.

As the depression moves along, the cold front gains on the warm front, and eventually overtakes it. This is only another way of saying that the warm air is slowly pushed off the ground, the cold air spreading underneath it, and eventually encircling the centre. The depression is then said to be *occluded*. After this stage is attained, its motion is slowed down, and it gradually dies away.

It remains to consider what happens at an individual station as the depression approaches, passes near, and recedes. We shall consider this in some detail for the passage over Holyhead of the depression shown in Fig. 13. It must be remembered, in the first place, that on the 21st the depression was centred over the south coast of Ireland, and that initially Holyhead was in the cold air in front of the depression. At the time represented by the chart shown in Fig. 13—7 a.m. on the 22nd—Holyhead was almost on the cold front, with the cold air just spreading over it. The records made by different instruments at Holyhead are reproduced in Fig. 15. Consider first the record of temperature, shown about the middle of the diagram. During the evening of the 21st and the early part of the following night, the sky was overcast, and so the temperature did not fall, but remained steady at about 50°. Then about 1.30 a.m. temperature

began to rise, reaching about 52° by 3 a.m.; afterwards it rose much more rapidly, reaching 55° some ten minutes later. A very gradual rise to 56° was followed by two hours of steady temperature. At 6.30 a.m. there was a rapid fall of about 2°, followed by steady temperature for 50 minutes, then a further fall of 2°, after which the temperature stayed at about 52°, the temperature of the cold air immediately behind the cold front. This means that the warm front passed the station at about 3 a.m., and that the cold front was double and passed between 6.30 a.m. and 7.20 a.m.

The rainfall is represented by the next curve, which measures the amount of rain which has fallen since the chart was placed in position, so that the slope of the line measures the rate at which rain fell at any time. The sharp drop of the curve from the top to the bottom of the chart shows the syphoning of the contents of the rain-gauge when full, and need not detain us here. The heaviest rain fell from 1 a.m. to 5 a.m., beginning well in advance of the warm front, and continuing for some time after the warm front had arrived over Holyhead. There was no appreciable rain after the passage of the cold front. Pressure, as shown by the lowest diagram, fell steadily until the passage of the cold front, and then rose rapidly.

The upper two diagrams in Fig. 15 represent the wind force and the wind direction, respectively. In the cold air in front of the depression the wind was East, with velocity increasing at first, then falling at the passage of the warm front; in the warm sector it was S. by W., and very gusty, with a mean speed of 25 miles per hour, while in the cold air in the rear of the cold front it was N.W., and, though its speed was little ~~less~~ than that in the warm air, it was far less gusty. These

pictures show that the essential changes in weather are associated with the so-called *polar front*, the line of separation between the warm and cold masses of air.

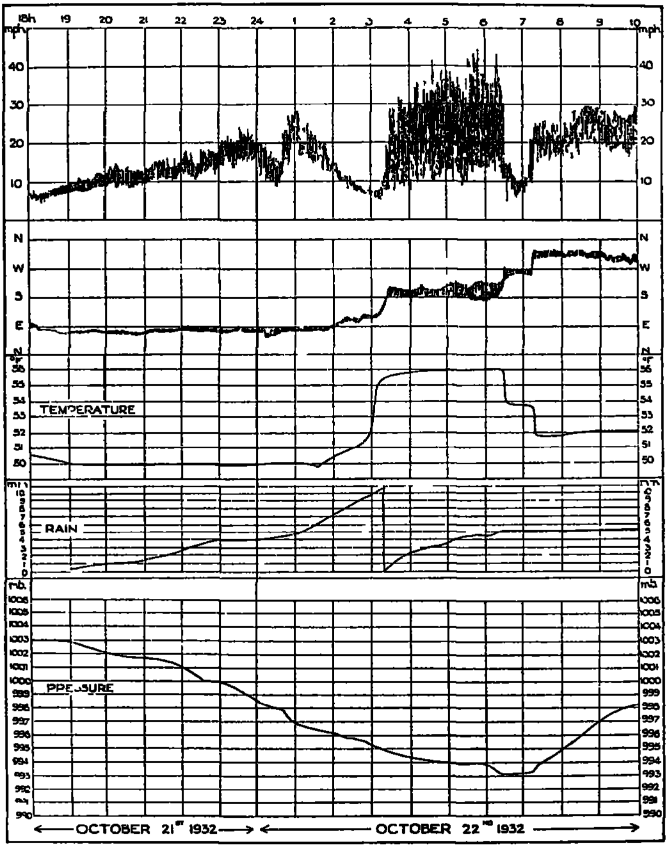


FIG. 15. AUTOGRAPHIC RECORDS AT HOLYHEAD ON OCTOBER 21–22, 1932.

The depression shown in Fig. 13 was 300 miles to the south-west of the position shown, at 6 p.m. on the 21st, and had moved about 450 miles to north-east by 6 p.m. on the 22nd. The forecaster, basing his predictions on the assumption that the depression would move parallel to the direction of the isobars in the warm sector, would in this case make a successful forecast. By timing the passage of the fronts over any particular place, he would be able to predict the times of occurrence of heavy rain at that place with reasonable accuracy, at least up to some hours after the time of the observations on which the chart was based.

The fronts drawn on the chart are thus of great value for forecasting the weather, and in particular for those short-period forecasts which are of special use to aviators. Any unbiased examination of official forecasts issued by any service in Europe or North America will show that in the last fifteen years there has been a marked improvement in forecasts for short periods ahead. The difficulty with which the forecaster is faced is rather that of foretelling when and where a new depression will form. On some occasions, too, it is far from easy to draw the polar front on the chart, or to separate the air in a depression into warm and cold masses. Occasionally it is possible to foresee the birth of a new depression, when masses of air of widely different temperatures are coming into juxtaposition. Most of the depressions which influence the weather of the British Isles are formed out in the North Atlantic, and since the receipt of observations from any particular part of the ocean depends on there being a ship in that locality at the time, it often happens that there is a lack of observations from the one region which is at the moment of special interest.

Enough has perhaps been said to show the general lines on which the work of the forecaster is done. The charts on which he plots his observations reveal from time to time a wide variety of distributions of isobars, so wide a variety that it appears safe to say that weather charts are like finger-prints—no two are ever alike. Each day has its own special chart, with its own special problem for the forecaster.

The forms which the isobars can take are dominated by the depression and the anticyclone, and the wedges, ridges, etc., which can occur between two or more of these structures. A little is said about anticyclones below, but we shall pass over the other possible structures.

The weather chart reproduced in some of the London morning papers is the 6 p.m. G.M.T. chart of the preceding day. In most of the newspapers the chart unfortunately covers only a very small area, but it is still sufficient to give the reader an idea of the weather situation. It can be recommended to the reader as an exercise to take the newspaper chart from day to day, and to draw on it the polar fronts, when this is possible. The earnest student who tries this will perhaps find it difficult at first, but it is worth trying. When the fronts can be drawn, the student will be able to trace the changes in temperature, wind-direction, visibility, etc., and to associate them with the passage of fronts. He will also be able to see why from time to time the forecasts fail completely. There are days when it is merely impossible to say what the next day will bring, but the unfortunate forecaster is not even then allowed to say, "We don't know."

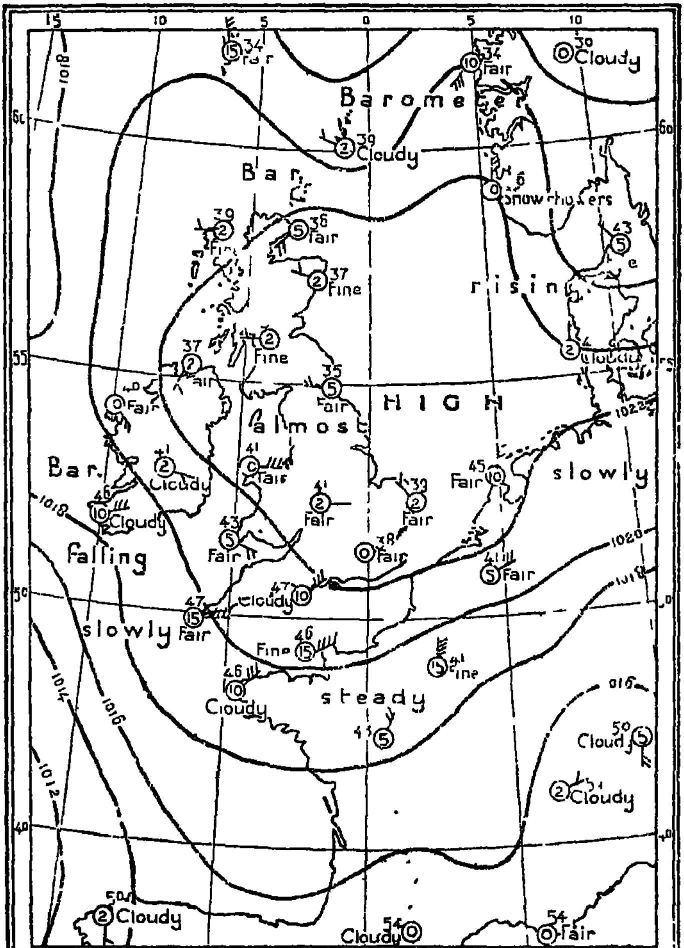


FIG. 16. THE ANTICYCLONE OF MAY 1, 1927.

THE ANTICYCLONE

A region of high pressure, surrounded by closed isobars, with the highest pressure at the centre, is called an anticyclone. A typical example is shown in the chart in Fig. 16, which represents conditions at 7 a.m. on May 1, 1927. The wind is everywhere light, particularly in the inner region, marked HIGH, and this is typical of all anticyclones. The weather is fair over a wide area, and this condition can in some cases persist for lengthy periods. Forecasts of fine spells can, as a rule, be issued only when a large anticyclone is settled over the country.

Anticyclonic weather is always distinguished by the absence of violent winds. The winds are, as in Fig. 16, everywhere light, and blow out across the isobars, but in such a direction as to form a clockwise whirl around the isobars. In summer, anticyclonic weather is fair or fine; but in winter fog is frequent, and even rain and snow are not impossible. At night the light winds fall off to a calm, and the cooling of the ground by radiation will then bring fog. Once foggy conditions are established in a winter anticyclone they may persist for days at a time.

Fig. 16 shows that at the time of observation the barometer was falling slowly to the west of Ireland, and rising slowly over Southern Scandinavia and Denmark, indicating that the anticyclone was slowly drifting eastward. The slow motion is characteristic of all anticyclones of North-western Europe, and the difficulty of the forecaster when an anticyclone is over the country is due not so much to its uncertain motion as to the suddenness with which it will sometimes collapse. An Austrian meteorologist named Hanzlik gave a rule that anticyclones may be divided into two classes: those

having warm centres, and those having cold centres. The warm type is more persistent, and moves more slowly, than the cold type. This rule is subject to many exceptions, and it is not safe to assume that because an anticyclone has a warm centre it will persist in giving warm weather for a long time. Even warm anticyclones may collapse suddenly.

OTHER TYPES OF ISOBARS

There are various other types of isobars, in which the distribution of weather has a typical form. For example, the wedge of high pressure is the region between two adjacent depressions. When the first depression passes over, the weather improves rapidly, and remains clear almost up to the edge of the next depression, when it suddenly deteriorates. It is this distribution of weather which gave rise to the saying, " It has cleared too quickly to last."

The region between two depressions and two anticyclones is known as a *col*. In it the weather is cloudy, often with rain, and in summer with thunderstorms.

When the isobars extend southward from the central part of a depression in the form of a trough, the trough is often referred to as a V-shaped depression. The essential feature of this type of structure is its resemblance to a cold front. At the central line of the trough there is a clash between a cold current from the north-west with a warmer current from a southerly direction. There will be heavy rain and squally winds at the passage of the line of separation of the two currents of air.

CLOUDS AND WEATHER FORECASTING

Were it possible to give rules for forecasting by the observation of clouds, this would be a most useful method for the amateur, since anyone can observe the clouds for himself. It is, however, possible to give a fairly complete picture of the sequence of cloud which occurs during the approach of a depression. The first sign of the approach of a depression is the rapid motion of cirrus from the west, the cirrus coming roughly from the centre of the depression, if the latter is in an early stage of development, but usually from a more southerly direction than the line from the observer to the centre of the depression, if the latter is in a late stage of development. After a few hours the cirrus is succeeded by cirro-stratus and alto-stratus, the cloud becomes steadily denser, and finally changes to nimbus, at the coming of the rain at the warm front of the depression. In the warm sector the cloud is mainly stratus and strato-cumulus, with a little cirrus and some alto-cumulus in advance of the cold front. At the cold front the cloud again changes to cumulo-nimbus. This gives place to stratus and alto-stratus, and then to broken cloud with blue sky.

The local observer could probably, with a little practice, make much use of the cloud sequence for forecasting. It is necessary to remember that certain types of cloud—notably strato-cumulus, alto-stratus, and to a less extent stratus—tend to clear at sunset, and to reappear at sunrise.

THE MEANING OF CHANGES OF PRESSURE

In an earlier chapter emphasis was laid on the fact that the barometer is an instrument which weighs the

column of air above unit area, the square centimetre, the square foot, or square inch. When pressure is falling over a particular area, it means that, by some mechanism or other, air is being removed from above that area. It has been shown, by a calculation which is by no means abstruse or difficult, that to hollow out a large depression, such as those which influence the weather of the British Isles, requires the removal elsewhere of amounts of air varying from a hundred thousand million tons to a hundred million million tons. Similarly, to build up a large anticyclone, such as that shown in Fig. 16, requires the accumulation over the area concerned of amounts of air of about the same magnitude. The precise nature of the mechanism by which this movement of air is brought about is as yet a mystery, though it is clear that the motion must take place largely in the upper air.

One thought provoked by the contemplation of these figures is the hopelessness of human effort to control the weather. It does not seem humanly possible to control a mechanism capable of removing millions of millions of tons of air from one region to another.

THE WEATHER FORECAST

We have given a very brief account of the use of weather charts in forecasting, not with the idea that the reader should endeavour to set up as a forecaster himself, but rather to give some idea of the organization behind the weather service, and of the difficulties which this service has to face. There is a routine side of the work of which no description has yet been given. As the weather will be different in different parts of the country, the whole of the British Isles is divided into

forecast districts, twenty-two in number. Each district is considered separately, and if necessary a separate forecast is written for each district. But in practice it is usually possible to bracket together some of the districts into groups for which a common forecast will hold. The forecast is normally restricted to about thirty words, and is often shorter than this, and in these few words the forecaster is expected to cover all the weather possibilities of hill and valley, moorland and seashore, within the district. On those occasions when a small part of the district gets peculiar weather, it is not to be expected that the forecast will cover all these peculiarities, and the success or failure of the forecast is to be judged by the general weather of the whole district which it covers. It is a not infrequent complaint that forecasts are too indefinite; but to those who make this complaint we would recommend a simple test. Take a piece of paper, and write on it, in not more than thirty words, a description of the weather of the past 24 hours in the forecast district in which you live. If in thirty words you can describe the weather of 24 hours, even after the event, more accurately than it was done by the forecaster, a complaint may be justifiable. But the occasions on which this can be done are not as frequent as the reader might imagine. If official forecasts are judged dispassionately, taking account of the limitations of space and of the size of the forecast districts, it will be found that the percentage of successes is very high. The forecaster is frequently compared to the racing tipster, to his detriment; but while a knowledgeable friend suggests that the successes of the very best newspaper tipsters never exceed 45 per cent., the forecaster's record is twice as good. Moreover, the forecaster is never allowed to say, "Some rain, if absent fine day,"

though there are occasions on which this might not be inappropriate.

Another of the trials of the forecaster is that he issues only one forecast, which will be expected to meet a wide variety of private needs. One reader wants to know if he should water his garden, another whether he should carry an umbrella, a third wants to fly to Paris, a fourth has a garden-party in the afternoon, a fifth wants to go fishing, and a sixth to play golf. For all these the same forecast in the morning paper is expected to supply knowledge, comfort, or warning.

HAS THE FORECAST FAILED?

It is always worth while to be able to check up the forecast, and to see whether it has failed completely or partially. The morning newspaper prints a forecast based on the 6 p.m. chart of the previous day. Sometimes the expectations of the forecaster have gone wrong by the time the forecast is in the hands of the newspaper reader. With a little practice it is possible to tell whether this has occurred.

If a barograph is available, it is generally possible to see whether the motion of a depression has followed the course expected. If the barograph shows that after falling steadily the pressure has begun to rise steadily, the worst of the depression has gone by. The same course can be inferred if the wind has gone round to north-west and the temperature has fallen. If the steady rain of the front of a depression has come earlier than was expected, the clearing as the depression passes away will also come earlier than was expected. If the wind, instead of going through S., S.W., to N.W., as anticipated from the passage of the centre of the depression to north, goes

from S. to S.E. and E., the depression has passed to south of us instead to north. Space does not permit of the elaboration of such rules; but the examples given show that it is frequently possible to see when the forecaster has partially failed, to explain the failure, and to make use of it. The average reader will find this a far more profitable exercise than constructing charts of his own with a view to making his own forecasts.

CHAPTER VIII

OTHER WEATHER DISTURBANCES

THE TROPICAL CYCLONE

THE tropical cyclone is a small depression in which the isobars are much more nearly circular, and the central pressure much lower, than in the ordinary depression of middle latitudes. The winds may attain hurricane force. They blow around the centre in the counter-clockwise sense in the northern hemisphere, and in the clockwise sense in the southern hemisphere. These small cyclones originate in low latitudes, between 6° N. and 20° N., and between 6° S. and 20° S. They have special names in different parts of the world, being known as *cyclones* in the Indian Ocean, as *hurricanes* in the West Indies, and as *typhoons* in the China Seas.

At the centre of a tropical cyclone there is a small region some 10 to 20 miles in diameter, known as the eye of the storm, in which the sky is clear, the winds light or calm, and the sea excessively turbulent. Surrounding this is a zone of winds of hurricane force, often exceeding 100 miles per hour, with sky overcast with heavy clouds, and torrential rainfall. The diameter of the cyclone—or rather of the area covered by the closed isobars of the cyclone—may be as much as 300 miles, but it is frequently much less. The pressure near its centre is usually as low as about 960 millibars, while at its outer edge the pressure is about 1020 millibars. There is thus a fall of about 60 millibars in 150 miles or less. This

should be contrasted with the depression of middle latitudes, in which a fall of 30 millibars in 300 miles is about the normal in an intense depression. The lowest pressure ever recorded at sea near the centre of a tropical cyclone was 886·8 millibars measured about 400 nautical miles east of Luzon in the Philippines, on August 18, 1927, while the lowest record at a land station in a cyclone was about 912 millibars, measured at Muroto in Western Japan, on September 21, 1934.

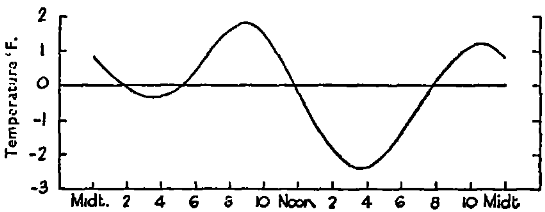


FIG. 17. THE VARIATION OF PRESSURE DURING THE DAY AT BATAVIA (LATITUDE 10° S).

The vertical scale shows the variation of the pressure from the mean value.

At places in the tropics and the adjoining regions, the barometer shows with great regularity a double wave in the course of each day, with maxima at 10 a.m. and 10 p.m., and minima at 4 a.m. and 4 p.m., local time. In Fig. 17 is shown such a curve for Batavia. On account of the regularity of this oscillation on all normal days, the coming of a cyclone which disturbs the usual form of the daily curve of the barograph is at once noticeable.

THE TORNADO

The tornado is a still smaller circular storm, often having a diameter of only 50 yards, and seldom exceeding a quarter of a mile in diameter. The winds are stronger

than any experienced in a tropical cyclone, and it is estimated that winds of 300 miles per hour sometimes occur. Since no structure can withstand such winds, no instrument in the direct path of a tornado survives to tell the tale. The tornado is a small but very intense depression, with very low pressures at the centre, and when the centre passes near a building, windows, doors, and walls are blown outwards by the excess of pressure inside the building over that outside. Usually the core of a tornado appears as a tube or a gigantic elephant's trunk, which swings about and seldom hangs vertically, often sloping at a considerable angle to the vertical.

In the centre of the tornado are violent ascending currents, bearing out the view that the essential condition for its formation is intense convection over a small area. The necessary contrasts of temperature seldom occur, except in some specially situated regions, such as the valley of the Mississippi, where, especially in spring, cold north-westerly currents meet warm currents from the Gulf of Mexico.

In that region a single tornado has been known to kill 700 people, to injure 2000 others, and to do material damage to the extent of three to four million dollars.

The convection may on occasion be produced artificially, as when a fire at San Luis Obispo destroyed nearly six million barrels of oil in 1925. Many tornadoes were observed over this fire, and also above the fire which consumed Tokio after the earthquake of September 2, 1923.

In the British Isles tornadoes are infrequent, and are always much less destructive than those of the United States. Examples of these occurrences in the British Isles were the tornado which did a fair amount of damage in South Wales on October 27, 1913, and one which

visited London on October 26, 1928. While such occurrences are rare in the British Isles, in the United States about 100 tornadoes occur each year, killing on an average about 300 people.

The dust-devil of the street corner is a younger brother of the tornado, but so much younger a brother that it is entirely harmless. This whirl does not show a definite preference for rotation counter-clockwise, but may spin in either direction.

THE WATER-SPOUT

When the conditions for the formation of a tornado occur over the sea, or over any extensive sheet of inland water, the result is a water-spout, which is a whirl of violent winds surrounding a core of cloud. The water-spout is usually small in dimensions ; but the winds in it may attain enormous speeds, and so do very great damage to any vessel in the immediate neighbourhood of its centre. Like the tornado, its centre is marked by a trunk-shaped cloudy core, which hangs from the lower side of a heavy nimbus cloud. Where the core touches the water, the sea is agitated, and spray and vapour appear to be sucked up into the core, giving the core the appearance of being made of water. The danger associated with the water-spout is not due to the water, but to the strong winds which surround the core.

THE LINE-SQUALL

The wedge of cold air which advances behind the cold front in the rear of a depression is checked at the ground by friction, and the cold air at 1000 to 2000 feet above the ground advances ahead of the air at the ground. From time to time the cold air in front of this advancing

nose bursts downward in heavy squalls. Any strongly-marked front will be a region of heavy squally winds, usually with a long roll of cloud showing the position of the nose of the cold air. This phenomenon is known as the line-squall, and it may be regarded as an intensified form of what happens at the cold front in any depression. It is usually accompanied by rain or hail. It is not a very great danger to aircraft when its form and nature are recognized.

THUNDERSTORMS

A fully developed thunderstorm is a storm in which there occur lightning, thunder, and rain. The thunder-cloud is a heavy cloud of the type of cumulo-nimbus. Different parts of the thunder-cloud have electrical charges, and it is now generally accepted that the upper part of the cloud has a charge of positive electricity, and the lower part a charge of negative electricity. Either charge may spark across the air to the ground, or a charge on one cloud may spark across to a charge of opposite sign on another cloud. The electric sparks which pass in either case are known as lightning-flashes. Even casual observation of thunderstorms shows that lightning-flashes sometimes pass from cloud to cloud, sometimes from cloud to ground.

The passage of lightning liberates small negative charges (called electrons) from molecules of air, and these charges are concentrated closely along the path of the lightning-flash. Their repulsion for one another produces a sound-wave in the atmosphere, and it is this sound-wave which is known as thunder. The light from the lightning-flash travels to the eye at the rate of 186,000 miles per second, while the sound of thunder travels at the rate of one mile in five seconds. If the time between

the flash being seen and the thunder being heard is noted, the distance of the flash is found by allowing one mile for every five seconds of the time-difference.

Thunderstorms may occur when the air is heated by contact with the ground warmed by the sun's rays, the heated air rising violently in consequence of its great excess of temperature over the air above it. Thunderstorms so formed occur mainly in the late afternoon or early evening. The heavy rainfall and the frequent hail, in these as well as in other thunderstorms, show that the ascent of large masses of damp air is an important factor in the development of thunderstorms. When very cold air comes in at high levels, or even when at the ground there is a violent clash of masses of air with a large difference of temperature, thunderstorms may be produced as a result of the forced ascent of the warm air from the ground. The necessary conditions for the formation of thunderstorms are often provided at the cold front of a depression, particularly near the centre of the depression. All types of thunderstorms which are not due to direct heating of the ground by the sun are as likely to occur by night as by day.

PROTECTION AGAINST THUNDERSTORMS

Before we can estimate the danger from lightning discharges, we must form some idea of the mechanism by which the discharge is produced. The reader is probably familiar with the fact that an electric current can spark across a small gap, giving a spark which is visible to the eye. This is a familiar fact to every motorist; but it is a far call from the spark which passes across the sparking-plugs of a petrol-engine, to the lightning-flash of several miles in length. Nor-

mally air is a poor conductor of electricity; but when it is subjected to very high electric forces, with enormous differences of potential over relatively short distances, it becomes a conductor of electricity over the region subjected to these conditions. The local breakdown in the insulating properties of the air appears to start within the charged cloud, and it develops a channel from the cloud, along which the electricity can pass. When this channel passes near to any electrical conductor, there is a violent rush of electricity along it. If the conductor along which this rush takes place has low electrical resistance, the current flows along it without doing any damage. If, however, the conductor which gets in the way of the channel of flow of the electricity from the cloud has high electrical resistance, the passage of the electric current through it may disrupt the conductor. If, for example, it is a tree, the part of the charge which passes inside the trunk may shatter the tree, while the part which flows over the surface of the trunk may spark across the air from the trunk to any person or object near to the tree.

Any building which towers above its neighbours will be certain to attract to itself many lightning-flashes which will miss lower buildings. Such a building should therefore be provided with a lightning-conductor. It has been found that a copper wire of not less than one-third of an inch in diameter makes an efficient lightning conductor. Its action is not so much to conduct lightning as to discharge from its point electricity of the right sign to neutralise the electric potential of the cloud, and so to prevent the development of the conditions which would produce a flash.

In the open there is very little danger of being struck, provided one avoids the near neighbourhood of good

conductors such as wire fences, since the wire will conduct any discharge which strikes it, and may be dangerous to anyone near it even some miles away from the point at which it is struck. It is dangerous to shelter under isolated trees, or specially high trees in a wood. It is best to seek shelter from a thunderstorm inside a building, rather than under any tree; and it is safer to remain in the open than to shelter under a tree. It is true that from time to time human beings are struck by lightning in the open, on golf-courses or football grounds; but the number of such fatalities is exceedingly small, when considered in relation to the enormous number of thunderstorms which occur in a year.

CHAPTER IX

AVERAGE CONDITIONS OVER THE GLOBE

WEATHER AND CLIMATE

It is convenient to distinguish between weather and climate by defining the climate of a place as the average conditions as represented by the pressure, temperature, humidity, rainfall, cloudiness, visibility, frequency of fog, etc., the averages being taken over a reasonably large number of years. We might, for example, draw up tables of the average values for each month of the year of each of the factors mentioned above, and so obtain what we should define as climatic tables. These in themselves would not tell the whole story: we should still want to know something of the variability of each of these factors, or of the extent to which each of them is liable to vary from the average from time to time. It is convenient to think of the average conditions as constituting the climate of a place, while the conditions of an individual day constitute the weather.

We have so far been mainly concerned with the weather, and in particular with the weather of places in middle latitudes of the northern hemisphere, with particular reference to the conditions over North-western Europe. It now remains to consider how conditions vary over the globe, and to see in what way the discussions in earlier chapters can be applied to explain or to summarize the facts of weather and climate over the whole of the globe. We shall, in the first place,

consider maps which show, for January and July (the months of extremes in most parts of the world), the average distribution of pressure, temperature, and wind over the globe. In examining these maps it must be borne in mind that the northern hemisphere is mainly a land hemisphere, and the southern hemisphere mainly an ocean hemisphere. Thus the extreme variations of temperature should show themselves more clearly in the northern than in the southern hemisphere. The maps for January and July do not tell the whole story. They are to be regarded as giving some idea of the extent to which conditions vary, rather than as a complete representation of the variations.

MEAN TEMPERATURE OVER THE EARTH

The average conditions in January and July, so far as temperature is concerned, are shown in the two maps in Figs. 18 and 19. Each line drawn on these maps passes through places having the same average monthly temperature. These lines are known as *isotherms*. In January the highest average temperature is contained in an irregular belt enclosed by the line marked 80°, which takes in a large part of the northern half of South America, the southern half of South Africa, the greater part of Australia, and narrow strip of the South Atlantic, Indian, and South Pacific Oceans. These strips are almost entirely south of the Equator, in the southern hemisphere, which has its summer in January. Temperature decreases as we go either northward or southward from here. The coldest region over the whole globe is in North-eastern Asia, where average temperatures below − 50° F. are to be met. There is also a centre of very low temperature, below −40° F., over the central

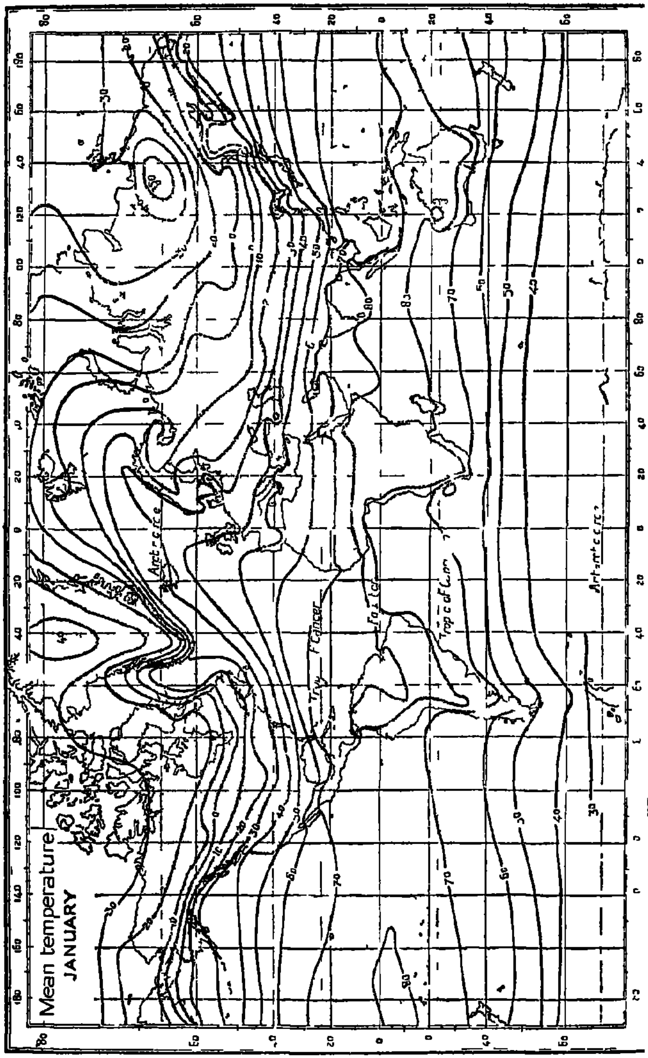


FIG 18 MEAN TEMPERATURES OVER THE GLOBE IN JANUARY

plateau of Greenland. Even a casual examination shows that in the northern hemisphere the temperature over the oceans is much higher than over the central part of the continents, anywhere outside the tropics.

Over the British Isles the average temperature is about 40° F., while in the same latitude near the southern end of Hudson Bay in Canada the average temperature is about 0° F., 32° below freezing point.

In July the highest temperatures are to be found over North-west Africa ; but the area covered by the isotherm of 80° is now much greater than in January, and is north of the Equator. The lowest temperatures shown on this map are over the fringe of the Antarctic continent. The differences between sea and land are less than in January ; but they are now in the opposite sense, the continents in the northern hemisphere being warmer than the oceans. Over the British Isles the average temperature of July is about 60° F., while in the same latitude near the southern end of Hudson Bay the average is 50° F.

To show how greatly the geographical position of a place can affect its temperature, we may compare London, with mean temperature of 39° in January, 63° in July, and a mean difference of 24° between the two, with New York, which is over 10° nearer to the Equator, and has mean temperature of 30° in January, 75° in July, and a mean difference of 45° between the two months. Again, Moscow is in almost exactly the same latitude as Edinburgh, but its mean temperature is 24° lower in January, and 7° higher in July.

The maps in Figs. 18 and 19 show only the mean conditions as represented by the average of a number of years. The average temperature of January or July at a particular station in an individual year may differ considerably from the value shown on the map. Still

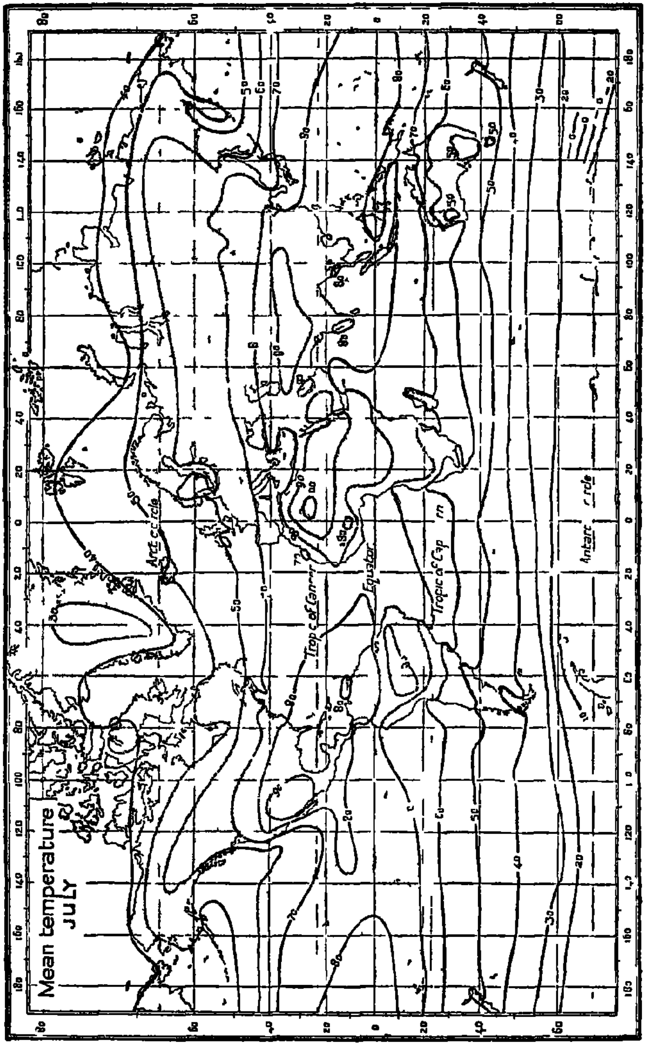
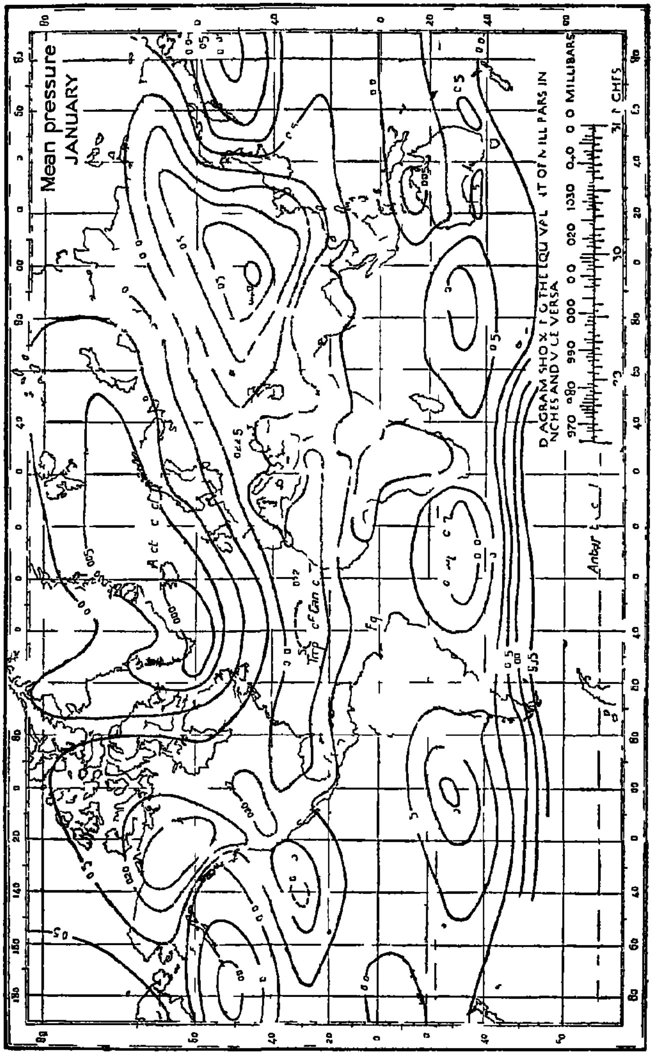


FIG 19. MEAN TEMPERATURES OVER THE GLOBE IN JULY.

more may the temperature of an individual day differ from this mean value, since the individual day's weather will depend on a number of factors, such as whether the sky is clear or cloudy, or the direction of the wind. Thus in winter in the British Isles a south-westerly wind brings high temperatures, and a north-westerly wind low temperatures, simply because they bring air from warm and cold regions respectively, and in winter a cloudy day with south-westerly wind is usually much milder than a sunny day with a north-easterly wind.

AVERAGE PRESSURE OVER THE GLOBE

In Figs. 20 and 21 are reproduced maps of the mean pressure over the globe, the lines drawn on the maps, known as *isobars*, representing the average pressure of the month. The continuous lines are labelled with a number which represents the average pressure in millibars. Let us first examine the January chart. We first notice a vast area of high pressure over Asia, the highest value, a little over 1040 millibars, occurring in longitude 100° E. Next comes an area of high pressure over North America, the highest values occurring in the north-east corner of the North American continent; but the isobar of 1015 millibars includes practically the whole of North America. There are centres of high pressure, over 1020 millibars, in the eastern North Pacific and in the North Atlantic. In the southern hemisphere there is a belt of high pressure, centred about latitude 30° S., which encircles the earth, but which has three centres at which pressure is highest, over the South Pacific, South Atlantic, and Indian Oceans. This belt is known as the sub-tropical belt of the southern hemisphere, and the region is frequently referred to as the "horse latitudes." There is a similar



IG 20 Mean Pressure over the Globe in January.

belt in the northern hemisphere, the centres of high pressure over the eastern Pacific and North Atlantic, mentioned above, being part of this belt; but the enormous area of high pressure which forms over Asia destroys any approach to symmetry in the northern hemisphere.

In the northern hemisphere there are two well-marked centres of low pressure: one over the Aleutian Islands in the Northern Pacific, generally named the Aleutian Low, and one over the North Atlantic. The last is no more than the imprint on the average conditions of the depressions which move across from southern Greenland to Iceland and Scandinavia, affecting the weather conditions of the North Atlantic and North-west Europe. We have already discussed these depressions briefly in Chapter VII.

Before going any further, let us endeavour to form some clear idea of the meaning of Fig. 20. We have seen that the pressure measured by the barometer, whose average values are shown in Fig. 20, is nothing more or less than a measure of the amount of air above each square foot of the ground. We can thus interpret the chart as showing that, for some reason which we shall not discuss here, the air tends to be piled up in excess in two belts centred in latitude 30° in each hemisphere, and that in the northern hemisphere (in winter) air tends to pile up over the continents at the expense of the oceans.

Coming to Fig. 21, the mean pressure distribution for July over the earth, we find that what we called the subtropical belt of high pressure in the southern hemisphere is strengthened a little, showing rather higher pressures than in January. In the northern hemisphere the two areas of high pressure over the North Pacific and North Atlantic have become much more extensive than in

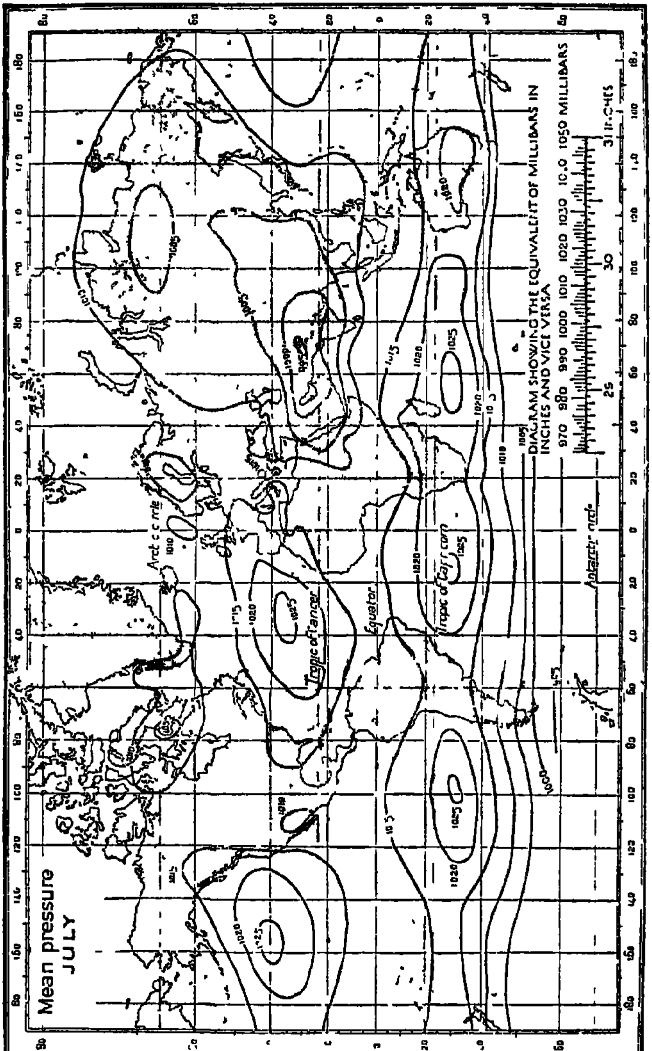


FIG. 21. MEAN PRESSURE OVER THE GLOBE IN JULY.

January. The Aleutian Low of the North Pacific has now disappeared, and the outstanding feature of the map is the change that has taken place over Asia, the high pressure centred in longitude 100° E. having disappeared, its place being taken by an area of low pressure centred over North-west India. Remembering that the average pressure over the earth is about 1013 millibars, we see from this chart that over the whole of Asia, with the possible exception of a tiny strip south of the Caspian Sea, pressure is below the average.

THE PREVAILING WINDS OF THE GLOBE

Buys Ballot's Law, which was mentioned on p. 76, can be used to deduce the average winds from the average distribution of pressure, and applying this law we find for January the following results :—

(1) North of latitude 35° the winds over the North Atlantic, North Pacific, and most of Europe and Northern Asia are westerly to south-westerly.

(2) South of latitude 30° the winds over the North Atlantic and North Pacific are north-easterly to easterly. These are the *Trade Winds.*

(3) At the Equator there is everywhere only a slight difference of pressure from place to place, and there is a belt of calms known as the *Doldrums,* centred on or near the Equator.

(4) In latitude 30° or so there is a belt of calms or light variable winds over the ocean, in the central part of the high-pressure belt.

(5) Over the extreme east of Asia the winds are northerly, blowing out of what Fig. 18 shows to be the coldest part of the northern hemisphere.

(6) Over the China Seas the wind is north-easterly, the so-called *North-east Monsoon.*

(7) Over the southern part of Asia the winds are easterly.

(8) In the southern hemisphere between the Equator and latitude 30° S., over all the oceans, there is a belt of south-east winds, known as the *South-east Trade Winds.*

(9) South of latitude 35° S., is a zone of westerly or north-westerly winds.

(10) The westerlies and the Trades are, as in the northern hemisphere, separated by a belt of calms or light variable winds.

We might have represented these facts by drawing arrows to represent the winds in Fig. 20; but the result would have been so to overload that map as to make it unreadable.

The July map in Fig. 21 shows little essential change in the southern hemisphere from the conditions which held in January. In the northern hemisphere the most noticeable difference is the disappearance of the Siberian anticyclone of January and the appearance of a centre of low pressure over the north-west of Asia, around which there is a circulation of winds in a counter-clockwise direction. Over most of India blows a broad south-westerly current of air which has started initially as a south-easterly current in latitude 30° S., and crossed the Equator. This current is known as the *South-west Monsoon,* and as it brings the copious rainfall of the months June to September, which controls the growth of India's crops, is of enormous economic importance. The reasons for this rainfall are discussed on p. 64. The southerly winds now blowing over the China Seas are there known as the southerly monsoon.

The prevailing winds which have been briefly described

above form what is known as the "general circulation" of the atmosphere. We must again stress the fact that the conditions described in this chapter are only average conditions over a number of years, and that any individual month, and still more any individual day, may have conditions differing widely from those shown on the maps included in this chapter. Without further consideration it is therefore not advisable to use these maps to solve any important problem, such as the choice of a permanent home. We shall proceed in the next chapter to consider some further features of the climates of the world.

CHAPTER X

THE WORLD'S CLIMATES

THE FACTORS WHICH DETERMINE CLIMATE

THE world is conventionally divided into a number of zones bounded by circles of latitude, defined as follows :—

(1) The north polar region, extending down to the Arctic circle in latitude 67° N.

(2) The north temperate zone, from the Arctic circle down to the Tropic of Cancer in latitude 23° N.

(3) The tropical zone, from 23° N. across the equator to 23° S.

(4) The south temperate zone, from 23° S. to the Antarctic circle in latitude 67° S.

(5) The south polar region, from latitude 67° S. to the south pole.

This conventional division can form a basis for a rough classification of the climates of the world, but it is not to be taken too literally. We shall see, for example, that parts of the north temperate zone have a climate which is far from temperate. The conventional classification fails because it does not take account of the lack of uniformity in the distribution of land and sea. We have already seen, on p. 36, that the temperature over the land tends to rise higher in summer and to fall lower in winter than over the oceans. At the fringe of a continent the more temperate conditions of the ocean are

extended inland for a considerable distance, if the prevailing wind blows from sea to land; but with increasing distance from the coast this modifying influence will diminish. And so it is clear that in considering the climate of any locality we must consider not only its latitude, but also its distance from the coast and the prevailing wind-direction.

Another factor to be considered is the height above sea-level, since the temperature of the air falls off at a rate of roughly 3° F. for every 1000 feet of elevation. Regions elevated above sea-level will therefore be colder than those at sea-level. The effect of elevation on precipitation cannot be stated simply, but has to be considered separately for each individual locality; it will depend in part on the nature of the slopes of the ground down to sea-level, and on the direction of the prevailing wind.

In practice, it is necessary to take the two factors mentioned above jointly into consideration. The modifying effect of winds from the sea on temperature in winter decreases with increasing distance from the ocean, and so the western shores of the oceans of middle latitudes are milder than the eastern shores. In a long passage over land, the westerly winds lose their content of moisture, so that when they meet high ground in the eastern parts of the continents they are not sufficiently moist to produce rainfall. The total precipitation, whether it is in the form of rain or snow, therefore decreases as we go eastward across Europe and Asia.

DIFFERENCES BETWEEN SUMMER AND WINTER

If we compare the division of the earth into climatic zones according to latitude, as given on p. 117, with the maps of mean pressure in Figs. 20 and 21, and the

deductions drawn from these maps as to the prevailing winds, we find that the prevailing winds are easterly in the polar regions, westerly in the temperate zones, and easterly in the tropical zones.

Comparing the maps of mean temperature for January and July given in Figs. 18 and 19, with the division of the globe into climatic zones, we find that the difference between the mean temperatures of the two months is least in the tropical zone, and increases with distance from the equator; so that in latitude 23° N. or S. it is rather less than 10° F. over the oceans, and round about 20° F. over the continents. Within the so-called temperate zones the difference between summer and winter temperatures still increases with distance from the equator, reaching an average value of about 70° over a large part of the continents in latitude 67° N. Over the open oceans in the northern hemisphere the annual variation of temperature does not, in general, exceed 35° F., while in the southern hemisphere, which is largely covered by ocean, it is little more than 10° F. anywhere over the ocean, and 20° F. over the land. In the north-eastern corner of Siberia there is a region where the average difference between summer and winter exceeds 110° F., this being the region shown in Fig. 18 as having an average January temperature of −50° F. or lower, while the average July temperature is about 60° F.

COLD AND WARM OCEAN CURRENTS

The difference between the eastern and western coasts of the continents, particularly in high latitudes, is enhanced by the effects of ocean currents. In the tropical zone, in both the Atlantic and Pacific Oceans, there are

broad ocean currents flowing westward, driven by the trade winds. Near the coast of North America most of the equatorial current of the Atlantic is deviated northward, flowing round the Gulf of Mexico and north-eastward across the Atlantic. Although several small streams branch off from it, most of the current flows north-eastward across the North Atlantic as the Gulf Stream, passing northward of the British Isles to the coast of Norway, bringing milder conditions to North-western Europe than could otherwise prevail. Another branch of the Atlantic equatorial current flows along the coast of South America, and there yields mild conditions, as shown in Figs. 18 and 19, by the bending southward of the isotherms along the eastern coasts of South America. A branch of the Gulf Stream sweeps southward to the Bay of Biscay and the west coast of Africa, where it arrives as a relatively cool current. The currents in the Pacific resemble those in the Atlantic. The main equatorial current of the Pacific divides into two, of which one, the Kurosiwo Drift, flows past Japan in a north-easterly direction across the North Pacific, while another branch, of which a portion flows down the California coast as a cool current, eventually flows southward along the eastern coast of Australia. There is also a warm current down the east coast of South Africa, and a cool current down the west coast of Australia. There is thus a very regular distribution of warm currents along the western coasts, and of cool currents along the eastern coasts, of the continents in middle latitudes. Here the prevailing winds are westerly, and the ocean currents enhance the winter contrast between the western and eastern coasts of the continents.

THE DAILY VARIATIONS OF TEMPERATURE

The daily variation of temperature is greatest over the central parts of the continents, and is very small or non-existent over mid-ocean, while over the fringes of the ocean the variations of temperature in the course of the day will depend on the changes in wind-direction more than on any other factor. The changes of the wind may bring air from the continent or from the ocean, and air from these two sources will, in general, have widely different temperatures. We shall not discuss further the daily variation of temperature over the ocean, believing it to be too small to be of any great importance.

We have already seen in Chapter III that the daily variation of temperature will be small if the atmosphere is very moist, and still smaller if the sky is cloudy; the daily variation will be great if the sky is clear and the air dry. The equatorial belt, being both cloudy and moist, should show little daily variation of temperature, while the desert regions beneath the sub-tropical anticyclones, being both dry and cloudless, should show large variations of temperature. Both these conclusions are borne out by the observed facts. In the equatorial belt the temperature is always high, by day and night, and the average difference between the highest day temperature and the lowest night temperature over the equatorial oceans is probably at most only about 2° F. Over the land the average difference between the extreme day and night temperatures is between 10° and 15° F.

Except for a narrow fringe of land on the margins of the oceans, the average daily range of temperature over the land areas of the northern hemisphere exceeds 20° F.; over the desert region of North America in Arizona, it exceeds 25° F., and over the desert regions of North

Africa and of Turkestan it exceeds 30° F. The daily range is lowest, for continental regions, over certain parts of the equator; in equatorial South America it is about 10° F., but in parts of equatorial Africa it is considerably higher than this.

Figs. 18 and 19 show that the average temperature in January or July, at any place on the equator, is not far above 80° F. Even the temperature of any individual day is never far from 80° F., and there is little difference between the temperatures of the day and the night. Indeed, it cannot be said that the climate of the equatorial zone is excessively hot, if we define hot as meaning the occurrence of high temperature. From time to time temperatures are observed, even in the British Isles, which are higher than ever occur at some places on the equator. It is not the temperature which makes the equatorial climate trying; the excessive moisture in the air is responsible for the discomfort which the white man feels in the equatorial regions. The air being moist even during the day, the slight fall of temperature during the night brings it to saturation point, but still leaves it with a temperature above 70° or even 75° F.

In the desert zones the night fall of temperature is so great that the nights are cool even in summer, and may be excessively cold in winter. The fall of temperature begins at sunset, and is exceedingly rapid during the first half-hour or so, becoming less precipitous as the night proceeds. The conditions do not vary much from day to day.

The average diurnal variation of temperature is less than 20° F. over a large part of Europe, but exceeds 20° F. over most of Asia and North America. The average values are less than over the desert regions, on account of the large number of cloudy days when the

temperature varies relatively little; but the actual difference between day and night in clear weather may be very much greater than the average value we have quoted. In middle latitudes snow-covered ground with a clear sky can lead to very large falls of temperature at night.

RAINFALL

It has been shown above that the division of the earth into climatic zones on the basis of temperature is quite practicable. When we come to consider rainfall, we find that, while it is possible to give a rough division of the globe into rainfall zones, this division is far less definite than that on the basis of temperature. Rainfall, as we have already seen in Chapter V, is produced when moist air is forced upward, either by clashing with a mountain range or other elevated ground, or with a current of colder air. It is in part a product of temperature, but still more of the circulation of the winds; and as the wind circulation is very complicated, it is not surprising that the distribution of rainfall should be still more complicated.

The inner tropics, near the Equator, form a region of very heavy rainfall, a region covering the doldrums of the Atlantic and Pacific Oceans and the equatorial belts of the continents. The average rainfall at the Equator amounts to about 75 inches per annum; but in places, as on the coast of Sierra Leone and Liberia, it amounts to 160 inches per annum. The large river basins of the Amazon and the Congo, which are in the equatorial belt, are both regions of heavy rain, and therefore of dense forest. With increasing distance from the Equator, the amount of rainfall in the year decreases steadily, until in the high-pressure belts centred about latitude 35° in

either hemisphere the rainfall is slight and uncertain. These belts are in both hemispheres the desert zones. In the northern hemisphere are the deserts of the Sahara, Arabia, and Arizona; while in the southern hemisphere are the Kalahari in South Africa, and the desert region of Australia. The deserts have developed in the belts of high pressure as a result of the very low rainfall, which in turn is due to the fact that these belts are regions of descending rather than of ascending air.

On the poleward side of the high-pressure belts are regions of prevailing westerly winds, the temperate belts in which variable weather is produced by the travelling depressions and anticyclones. In these belts moderately heavy rain falls over the ocean, and also over the western parts of the continents of the northern hemisphere. The central and eastern parts of the Eurasian continent and of North America are relatively dry on account of their distance from the oceans to the west, from which the winds come. But everywhere within the temperate belt of the northern hemisphere rainfall is almost entirely brought by the passage of depressions, and so occurs intermittently and irregularly.

On the poleward side of the temperate belts are the polar regions, which are relatively dry because the air is so cold that it can carry only a small amount of moisture.

SUMMARY OF THE CLIMATES OF THE GLOBE

We are now in a position to summarize briefly the climatic zones of the earth. The limitations of space make it impossible to give more than the roughest outline of the conditions in any zone, and the reader who desires to find further details is recommended to consult a standard textbook on Climatology.

(1) The tropics: Hot, damp, cloudy, and rainy.

(2) The high-pressure belts in both hemispheres: Hot and dry; mostly with clear skies, giving deserts over the land.

(3) Temperate belts: over the oceans and the western fringes of the continents, temperate, very cloudy, rainy. Over the central and eastern parts of North America, Europe, and most of Asia, hot summers and cold winters, becoming less cloudy and drier from west to east.

(4) Polar regions: Cold and dry.

WET AND DRY SEASONS

The most casual inspection of rainfall records from different stations shows that, while some places have well-defined "wet" and "dry" seasons, others have no clearly defined distinctions between one month and another. Figs. *22a* and *22b* reproduce the average monthly rainfall for a number of places. Over a large part of India most of the rain comes during the monsoon season of June to September, and this is true of any individual year. In London, October has on the average a higher rainfall than any other month; yet in any individual year the highest rainfall may come in any month of the year. These two examples may serve to show how difficult it is to give any satisfactory summary in a few words of the seasonal variations of rainfall.

In the equatorial zone, between 10° N. and 10° S., the rainfall seasons vary considerably from place to place, both as to the time of year at which they come and as to the intensity of the rainfall. On the equator, every month is liable to be rainy; but it becomes a little rainier than the average in April and October, and a little less rainy than the average about January and July.